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AMERICAN GEOPHYSICAL UNION

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GENERAL

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STATUTES AND BY-LAWS OF THE AMERICAN GEOPHYSICAL UNION

(As amended to 1926)

PREAMBLE

The American Geophysical Union is hereby established by the National Research Council. It supersedes the "American Section of the proposed International Geophysical Union." The American Geophysical Union is the American National Committee of the International Geodetic and Geophysical Union and the Executive Committee of the American Geophysical Union is the Committee on Geophysics of the National Research Council. The American Geophysical Union is constituted as follows:

ARTICLE 1

Objects

(a) To assist in carrying out the objects of the International Geodetic and Geophysical Union, which are: To promote the study of problems concerned with the figure and physics of the Earth; to initiate and co-ordinate researches which depend upon international co-operation, and to provide for their scientific discussion and publication; and to facilitate special researches, such as the comparison of instruments used in different countries.

(b) To promote and co-ordinate the study of the various branches of geodesy and geophysics in the United States of America and its outlying territories.

ARTICLE 2

Membership

The membership of the American Geophysical Union shall be as follows:

(a) Those who composed the membership of the "American Section of the proposed International Geophysical Union" on July 1, 1919.

(b) Those who may be appointed by the Executive Board of the National Research Council upon nominations submitted by the Executive Committee of the American Geophysical Union.

(c) The Chairman of the Division of Foreign Relations, the Chairman of the Division of Physical Sciences, the Chairman of the Division of Chemistry and Chemical Technology, the Chairman of the Division of Geology and Geography, and the Chairman of the Division of Biology and Agriculture, of the National Research Council, members *ex officio*.

(d) The American officers of the International Geodetic and Geophysical Union and of its Sections, members *ex officio*.

ARTICLE 3

Sections

The American Geophysical Union shall be divided into Sections, in accordance with the organization of the International Geodetic and Geophysical Union, as follows: (a) Geodesy; (b) Seismology; (c) Meteorology; (d) Terrestrial Magnetism and Electricity; (e) Oceanography; and (f) Volcanology. The members shall designate the Section, or Sections, to which they will belong. The *functions of the Sections*, in their respective fields, shall be the promotion of the objects of the American Geophysical Union.

ARTICLE 4

Officers of the American Geophysical Union

The *Officers of the American Geophysical Union* shall consist of a chairman and a vice-chairman, elected to serve for a period of three years, and not to be eligible for immediate re-election to their respective offices; and a general secretary, to serve for a period of three years.

ARTICLE 5

Officers of Sections

The *Officers of the Sections* of the American Geophysical Union shall consist for each Section of a chairman, a vice-chairman, and a secretary, whose eligibility and periods of office shall correspond to those of the Union. The Chairman of each Section shall have the power to appoint, with the right to vote, a representative of the Section to such meetings of the Executive Committee of the Union as he may be unable to attend.

ARTICLE 6

Executive Committee

The *Executive Committee* shall consist of the chairman, the vice-chairman, and the general secretary of the American Geophysical Union, and of one representative from each of the sections of the Union, who shall be the chairman thereof or a member appointed by him; and, in addition, *ex officio*, the American officers of the International Geodetic and Geophysical Union, and of its Sections, the chairman of each of the Standing Committees of the American Geophysical Union, and the chairman of each of the following Divisions of the National Research Council: Foreign Relations, Physical Sciences, Chemistry and Chemical Technology, Geology and Geography, and Biology and Agriculture. This Committee shall have charge of all administrative matters of the American Geophysical Union, and shall be the representative of the Union in its relations with the National Research Council and with the International Geodetic and Geophysical Union. The Executive Committee, in consultation with the Sections, shall nominate to the Executive Board of the National Research Council delegates, or representatives, to the meetings of the International Geodetic and Geophysical Union and of its Sections, in accordance with the regulations fixed by the International Research Council for the voting power of the United States of America.

ARTICLE 7

Annual Meetings

The American Geophysical Union and its Sections shall meet annually at such time and place as may be chosen by the Executive Committee of the Union. The officers of the Union and of the Sections shall be elected at this annual meeting.

ARTICLE 8

Special Meetings

Special Meetings of the American Geophysical Union, or of its Sections, may be called when necessary by the respective chairmen.

ARTICLE 9

By-Laws

The American Geophysical Union is authorized to enact such by-laws as may be necessary for the performance of its functions and duties.

ARTICLE 10

Amendments

Amendments to the Statutes of the American Geophysical Union shall be subject to the approval of the National Research Council.

BY-LAWS

The fiscal year of the American Geophysical Union shall conform to the fiscal year of the National Research Council.

Standing committees on Statutes and By-Laws, on Membership, on Meetings, and on Budget, shall be appointed for the ensuing fiscal year by the Chairman-elect of the Union prior to the beginning of each year.

All committees of the American Geophysical Union shall terminate at the end of the fiscal year for which they may be appointed.

Meetings of the Union shall be called at least thirty days in advance, and those present at the meeting shall constitute a quorum.

Meetings of the Executive Committee shall be called by the Chairman, and those present shall constitute a quorum.

Final action shall not be taken by the Executive Committee on matters affecting any Section in the absence of the Chairman of such Section, or his representative.

No mail ballot shall be closed until at least thirty days after the date of issue.

After thirty days' notice has been given, amendments to the Statutes (all of which are subject to the approval of the National Research Council) may be voted on either by mail or at a regular meeting of the Union.

Amendments to the By-Laws may be proposed either by mail or at a regular meeting; when voted on by mail they require for adoption a majority vote of

the members; when voted on at a regular meeting they require for adoption a three-fourths vote of the members present.

Any amendment to the Statutes or By-Laws proposed by at least five members shall be submitted for vote to the members of the Union by the Executive Committee.

A member of the American Geophysical Union may be dropped from the Union by a three-fourths vote of the members of the Executive Committee.

Statutes and By-Laws adopted by a Section shall not conflict with the provisions of the Statutes and By-Laws of the Union.

Matters pertaining to a Section or Sections, and not pertaining to the Union as a whole, shall be acted upon by the Section or Sections concerned.

ALPHABETICAL ADDRESS LIST OF MEMBERS OF THE AMERICAN GEOPHYSICAL UNION[1]

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[1]Total number of members on July 1, 1926, is 71. The letters following each name indicate the sections with which the member is affiliated, these being (*a*) Geodesy, (*b*) Seismology, (*c*) Meteorology, (*d*) Terrestrial Magnetism and Electricity, (*e*) Oceanography, and (*f*) Volcanology.

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The Chairman, Division of Chemistry and Chemical Technology, National Research Council.
The Chairman, Division of Geology and Geography, National Research Council.
The Chairman, Division of Biology and Agriculture, National Research Council.

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Vice-Chairman, G. W. Littlehales (1926-1929)
General Secretary, J. A. Fleming (1925-1928)

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Meteorology	H. H. Kimball (1926-1929)	G. W. Littlehales (1926-1929)	A. J. Henry (1926-1929)
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Volcanology	T. A. Jaggar, Jr. (1926-1929)	F. E. Wright (1926-1929)	R. B. Sosman (1925-1928)

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[1] The affiliations with sections of the ex officio members are not shown in these lists, owing to inevitable changes from year to year.

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W. E. Parker
W. J. Peters
W. F. G. Swann

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R. L. Faris
J. A. Fleming
Harvey C. Hayes
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Rogers Wells
Bailey Willis

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OFFICERS SINCE ORGANIZATION

OFFICERS OF THE AMERICAN GEOPHYSICAL UNION[1]

CHAIRMAN	VICE-CHAIRMAN	GENERAL SECRETARY
William Bowie, 1920-22	Louis A. Bauer, 1920-22	H. O. Wood, 1919-21
Louis A. Bauer, 1922-24	Arthur L. Day, 1922-24	W. J. Humphreys, 1921-22
H. F. Reid, 1924-26	*H. S. Washington*, 1924-26	William Bowie, 1922-25
H. S. Washington, 1926-29	G. W. Littlehales, 1926-29	*J. A. Fleming*, 1925-28

OFFICERS OF THE SECTIONS[1]

SECTION	CHAIRMAN	VICE-CHAIRMAN	SECRETARY
(*a*) Geodesy	William Bowie, 1920-22	J. F. Hayford, 1920-22	H. O. Wood, 1920-22
	J. F. Hayford, 1922-24	R. L. Faris, 1922-24	William Bowie, 1922-25
	R. L. Faris, 1924-26	J. F. Hayford, 1924-25	*W. D. Lambert*, 1925-28
	William Bowie, 1926-29	*William Bowie*, 1925-26	
		F. E. Wright, 1926-29	
(*b*) Seismology	H. F. Reid, 1920-22	J. C. Branner, 1920-22	H. O. Wood, 1920-22
	W. J. Humphreys, 1922-24	J. B. Woodworth, 1922-24	*D. L. Hazard*, 1922-28
	J. B. Woodworth, 1924-26	*L. H. Adams*, 1924-26	
	L. H. Adams, 1926-29	N. H. Heck, 1926-29	
(*c*) Meteorology	C. F. Marvin, 1920-22	W. J. Humphreys, 1920-22	*A. J. Henry*, 1920-29
	E. H. Bowie, 1922-24	R. DeC. Ward, 1922-24	
	C. G. Abbot, 1924-26	*H. H. Kimball*, 1924-26	
	H. H. Kimball, 1926-29	G. W. Littlehales, 1926-29	
(*d*) Terrestrial Magnetism and Electricity	Louis A. Bauer, 1920-22	W. F. G. Swann, 1920-22	*J. A. Fleming*, 1920-29
	W. F. G. Swann, 1922-24	Louis A. Bauer, 1922-24	
	Louis A. Bauer, 1924-26	*N. H. Heck*, 1924-26	
	N. H. Heck, 1926-29	J. H. Dellinger, 1926-29	
(*e*) Oceanography	G. W. Littlehales, 1920-22	A. G. Mayor, 1920-22	J. T. Watkins, 1920
	J. P. Ault, 1922-24	G. W. Littlehales, 1922-24	W. E. Parker, 1920-23
	N. H. Heck, 1924-26	*W. J. Peters*, 1924-26	*G. T. Rude*, 1923-26
	T. W. Vaughan, 1926-29	*G. T. Rude*, 1926-29	A. H. Clark, 1926-29
(*f*) Volcanology	H. S. Washington, 1920-22	R. A. Daly, 1920-22	H. O. Wood, 1920-21
	L. H. Adams, 1922-24	T. A. Jaggar, Jr., 1922-24	*R. B. Sosman*, 1921-28
	T. A. Jaggar, Jr., 1924-29	*N. L. Bowen*, 1924-26	
		F. E. Wright, 1926-29	
(*g*) Geophysical Chemistry[2]	Arthur L. Day, 1920-22	F. W. Clarke, 1920-22	R. B. Sosman, 1920-24
	H. S. Washington, 1922-24	Whitman Cross, 1922-24	

DATES OF ANNUAL MEETINGS OF UNION AND OF ITS SECTIONS

First, April 23, 1920
Second, April 18-20, 1921
Third, March 6, 8, 1922
Fourth, April 17-19, 1923
Fifth, May 1-3, 1924
Sixth, April 30, May 1, 1925
Seventh, April 29, 30, 1926

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[1] The names of the officers for the seventh annual meeting are indicated by italics.
[2] Discontinued May 31, 1924, as International Union failed to provide for such a Section.

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RESOLUTIONS

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RESOLUTION ON THE VARIATION OF LATITUDE

(Submitted by Section of Geodesy)

Whereas, The problem of the variation of latitude concerns not only astronomy, but also geophysics in its broadest sense, as is evidenced by the appointment by the International Astronomical Union and the International Geodetic and Geophysical Union of a joint committee consisting of astronomers, geodesists, and geophysicists to confer with and advise the officers of the organizations conducting the present latitude-variation stations on an international cooperative plan, and

Whereas, The accepted method of studying this problem is by the operation of a chain of latitude stations on the same parallel, all using a common program of observations, and

Whereas, The great extent of the United States in longitude suggests that its contribution to this important piece of international work should include more than the maintenance of the present single station at Ukiah, California, and

Whereas, The original number of latitude-variation stations on the thirty-ninth parallel of latitude has been reduced from six (three of which were in the United States) to three, a number found to be too small for the adequate study of the many elements that are now known to enter into this problem, and

Whereas, Of the abandoned latitude stations that at Gaithersburg, Maryland, would be the easiest to re-establish and the most useful, and

Whereas, The importance of reoccupying this station is recognized by experts and has been urged many times in the unanimous reports of committees of the American Section of the International Astronomical Union, duly adopted by the Section, and

Whereas, The International Astronomical Union, meeting at Cambridge, England, in 1925, has urged the Director of the United States Coast and Geodetic Survey to endeavor to secure the reoccupation of Gaithersburg, therefore be it

Resolved, That the American Geophysical Union strongly recommends that observations be resumed at the Gaithersburg latitude station, preferably under the direction of the United States Coast and Geodetic Survey, which now supervises the work at the latitude station at Ukiah, California, and be it further

Resolved, That copies of this resolution be sent to the President of the United States, to the Secretary of Commerce, to the Director of the United States Coast and Geodetic Survey, to the President of the National Academy of Sciences, to the President of the American As-

tronomical Society, to the President of the Geological Society of America, and to the President of the Seismological Society of America.

RESOLUTION CONCERNING THE TOPOGRAPHIC MAPPING OF THE UNITED STATES

(Submitted by Section of Geodesy)

Whereas, Accurate knowledge of the geographic positions, elevations, and configuration of the ground is essential to the efficient carrying on of geophysical investigations, and

Whereas, The results of these investigations have great scientific and practical value, therefore be it

Resolved, That the American Geophysical Union heartily endorses the plan of the United States Government to complete the topographic mapping of this country in the near future, and be it further

Resolved, That copies of this resolution be sent to the President of the United States, the President of the Senate, and the Speaker of the House of Representatives.

RESOLUTION ON GREATER UNIFORMITY IN PYRHELIOMETRIC MEASUREMENTS

(Submitted by Section of Meteorology)

Whereas, In the interest of convenience to investigators, greater uniformity in pyrheliometric measurements is desirable, therefore be it

Resolved, That the Meteorological Section (*c*) of the International Union of Geodesy and Geophysics be requested (1) to authorize its Commission on Solar Radiation to encourage in every way possible the maintenance of an international network of pyrheliometric stations for obtaining directly comparable measurements of the intensity of solar energy, (2) to include as many high-level stations as practicable in this network, and (3) to provide that, especially at high-level stations, attention be given to the measurement of the ultra-violet radiation and the ozone content of the atmosphere, and

Resolved, That the above-named Commission be authorized to cooperate with the Commission on Solar Radiation of the International Meteorological Committee in arranging for the intercomparison of substandard pyrheliometers for use in different countries, in preparing a program to be recommended for daily observations, and in securing prompt publication of monthly summaries of results, and

Resolved, further, That a copy of these resolutions be sent to the General Secretary of the International Geodetic and Geophysical Union

(Colonel H. G. Lyons), and to the Chairman of the Committee of the International Research Council for the Study of Solar and Terrestrial Relationships (Dr. S. Chapman, Imperial College of Science, London, England).

RESOLUTION ON SOLAR-RADIATION STATIONS AND RESULTS

(Submitted by Section of Meteorology)

Whereas, In view of the probable early completion of arrangements in southwest Africa for determining the constant of solar radiation, and the availability thereafter of such data from three stations, one each in North America, South America, and southwest Africa, and

Whereas, It is claimed that the provisional values of these determinations are an aid in weather forecasting, therefore be it

Resolved, That the American Geophysical Union expresses its great pleasure and satisfaction in the purpose of the Smithsonian Institution and the National Geographic Society to maintain the stations abovementioned for a period of at least four years, and be it further

Resolved, That the Astrophysical Observatory of the Smithsonian Institution be, and hereby is, requested to make the data of these stations available at the earliest practicable moment to all organized weather services, and

Resolved further, That a copy of these resolutions be sent to the Secretary of the International Meteorological Committee (Th. Hesselberg, Oslo, Norway), for transmission to the various governmental weather services adhering to that Committee, with a request for cooperation in the attempt to correlate data of solar radiation with terrestrial weather, and a copy also to the General Secretary of the International Geodetic and Geophysical Union (Col. H. G. Lyons).

RESOLUTION ON GRAVITY AT SEA[1]

(Endorsed by sections of Geodesy and Seismology for favorable consideration)

Whereas, A method for the determination of gravity at sea with an accuracy comparable to that obtainable on land has been perfected by Dr. F. A. Vening Meinesz of the Dutch Geodetic Commission and has been successfully used by him on two voyages on a submarine, one from Holland to Java by way of the Suez Canal, and the other from Holland

[1]Adopted by Division of Geology and Geography at its annual meeting of April 24, 1926, and approved by Division of Foreign Relations of National Research Council on April 25, 1926.

to the Suez Canal, and the method will again be used by Dr. Meinesz during the present summer on a voyage from Holland to Java by way of the Panama Canal, and

Whereas, The deficiency in gravity observations over the ocean areas and inland seas is retarding geological and geophysical studies, and

Whereas, The desirability of making gravity observations at sea has been recognized by the Section of Geodesy of the International Geodetic and Geophysical Union which, by suitable resolutions, has urged all nations having navies to make observations similar to those made by Dr. Meinesz, therefore be it

Resolved, That the Division of Geology and Geography of the National Research Council of the United States commends in the highest terms the Dutch Geodetic Commission and the Dutch Navy for making it possible for Dr. Meinesz to carry on his gravity observations at sea and expresses the hope that every maritime nation may find it possible to supplement the magnificent work of Dr. Meinesz by making additional gravity determinations at sea, especially near its own coasts. We especially commend this work to the Navy Department and to the Coast and Geodetic Survey of the United States of America, and

Be it further Resolved, That a copy of this resolution be sent to the President of the United States, to the Secretary of State, to Dr. F. A. Vening Meinesz, to Dr. J. J. Mueller, President of the Dutch Geodetic Commission, to the Admiral of the Dutch Navy, to the Secretary of the United States Navy, to the Secretary of Commerce, and to the Director of the United States Coast and Geodetic Survey.

REPORTS AND PAPERS

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GENERAL MEETING

(Washington, D. C., April 30, 1926)

SYMPOSIUM ON THE CONSTITUTION OF THE EARTH

THE DENSITY OF THE EARTH AND THE INFERENCES TO BE DRAWN FROM IT

P. R. Heyl

The first recorded estimate of the density of the Earth was made by Newton. It is to be described rather as a guess than as an estimate, as may be seen by reading Newton's original words (Principia, Book III, Prop. X, Theorem X):

"But that our globe of Earth is of greater density than it would be if the whole consisted of water only, I thus make out. If the whole consisted of water only, whatever was of less density than water, because of its less specific gravity, would emerge and float above. And upon this account, if a globe of terrestrial matter, covered on all sides with water, was less dense than water, it would emerge somewhere; and the subsiding water falling back, would be gathered to the opposite side. And such is the condition of our Earth, which in a great measure is covered with seas. The Earth, if it was not for its greater density, would emerge from the seas, and, according to its degree of levity, would be raised more or less above their surface, the water of the seas flowing backwards to the opposite side. By the same argument, the spots of the Sun, which float upon the lucid matter thereof, are lighter than that matter. And however the planets have been formed, while they were yet in fluid masses, all the heavier matter subsided to the center. Since, therefore, the common matter of our Earth on the surface thereof is about twice as heavy as water, and a little lower, in mines, is found about three or four, or even five times more heavy, it is probable that the quantity of the whole matter of the Earth may be five or six times greater than if it consisted all of water; especially since I have before showed that the Earth is about four times more dense than Jupiter."

Since Newton's day, a number of different experimental methods have been employed in the attempt to determine the density of the Earth. By far the best method is that of the torsion balance, first used by Cavendish in 1798. He obtained for the density of the Earth the value 5.45.

Other experimenters during the nineteenth century obtained rather widely differing values by this method. The accepted figure at present is that obtained independently by Boys in England and Karl Braun in Bohemia about 1896. Their values happen to agree to three decimal

places, 5.527, but the separate observations vary in the second place of decimals. Consequently, Poynting in his excellent article on "Gravitation" in the Encyclopedia Britannica considers the value to be 5.53.

A value of 5.53 was obtained about the same time by Eötvös, but he did not consider his work at all accurate. It was undertaken as a side-issue, to test the sensitivity of a torsion balance which Eötvös had constructed for other purposes. His attracting masses were built up of blocks of lead, and no accurate allowance could be made for the interstices.

Dr. G. K. Burgess, the present Director of the Bureau of Standards, obtained in 1901 the figure 5.55. This work was undertaken with a time limit upon the experimenter, being thesis work for a degree at the Sorbonne. Dr. Burgess always retained his interest in the question, and felt that he would like to repeat the work under more favorable conditions. When he became Director of the Bureau of Standards in 1923 he saw his opportunity, for it is only with the facilities of such an institution to draw upon that it may be hoped to improve upon the excellent work of Boys and Braun.

The redetermination of this important constant at the Bureau of Standards is still in progress. The program of observations will probably be concluded in December of the present year, but the computations are very heavy and will take some time longer. The work has advanced to a stage where it is indicated that the first three figures (5.53) of Boys and Braun will be verified, and a fourth figure obtained in addition.

Since the average density of the crust of the Earth is between 2 and 3, it follows that the center of the Earth must, as Newton suspected, be composed of much heavier materials. Other lines of evidence, to be described by the speakers following, indicate the probability that the center of the Earth is a large ball of iron.

Bureau of Standards,
U. S. Department of Commerce,
Washington, D. C.

SEISMIC WAVES, AND WHAT WE LEARN FROM THEM AS TO THE INTERIOR OF THE EARTH

ROBERT B. SOSMAN

Mr. Adams has asked me to present this subject, not because I have made any important new contributions to it, but because I recently compressed what we know of the interior of the Earth into ten one-hour lectures, which material was then further abstracted into a one-hour lecture at another institution. It is only one additional step in high-pres-

sure technique, with which Mr. Adams is so familiar, to compress the one-hour lecture into ten minutes.

The title says "seismic waves." I would broaden it to "elastic waves," for the earthquakes are not essential to this branch of the science of the Earth's interior structure, a science that I have ventured to call *geotaxology*. Earthquakes are only a convenient means, though not a very satisfactory one, for supplying elastic waves. Future progress in the science will undoubtedly see an increasing use of artificial and therefore controllable waves, such as may be produced by an explosion or by the fall of a heavy body.

If the Earth were a homogeneous and isotropic body, a mechanical impulse at a point in its interior would send out two spherical waves, rapidly becoming distinct and independent. One is the compressional, longitudinal, or sound wave, whose speed V_c is given by $V^2_c = (K + 4/3\ R)/D$, where K is the incompressibility, R is the rigidity, and D is the density The other is the distortional or transverse wave, whose speed is given by $V^2_d = R/D$. At the free surface the impulse produces a complex set of resultant waves, of which the well-known Rayleigh wave is a special case. In a radially heterogeneous Earth these various types of interior and surface waves still persist, though modified in character.

To obtain information concerning those parts of the Earth through which the elastic waves have traveled, it is necessary to make quantitative measurements on them. The measurable quantities fall naturally into two groups, namely: (*A*) Quantities peculiar to the waves themselves, such as wave-speed, group-speed, period, amplitude, and extinction; (*B*) quantities relating the waves to the Earth, such as speed of surface appearance, angles of emergence (true and apparent), and direction of vibration.

For a given type of waves, such as the compressional, these quantities can be measured singly, and they can also be combined in various ways. Furthermore, taking a given quantity or combination, comparisons can be made between compressional and distortional types. Altogether there results a large variety of possible kinds of quantitative information.

Among the principal deductions already made from quantitative measurements of this kind are the following results relative to the Earth's interior:

(1) The Earth is essentially a solid object. Compressional waves can be transmitted by a liquid or a gas, but the transmission of distortional waves implies rigidity, at least to forces of short period. If there is any liquid material in the outer mantle, it must be confined to

small pockets or thin layers. It is not yet certain that distortional waves are transmitted by the core, but if they are, as now seems probable, then the entire Earth is proved rigid.

(2) Poisson's ratio for the material of the interior is not far from the value 1/4, being a little above rather than below this. The range of actual values obtained from the speeds of the two waves is 0.25 to 0.28.

(3) The Earth is probably spherically homogeneous below a depth of perhaps 200 kilometers; that is, its properties at any point on an imaginary interior surface of constant radius are the same as at any other point on that surface. This follows from our experience that the average time-curve becomes more precise as more data are obtained from different parts of the Earth. As unexplained minor discrepancies still persist, however, it will be best to say only that there is as yet no definite evidence *against* spherical homogeneity and nothing in the elastic-wave data which would support any hypothesis of deep-penetrating spherical inhomogeneities or wedges.

(4) The Earth has a core whose properties are distinctly different from those of the rest of the Earth. The radius of the core is about 3,500 kilometers and the depth to its surface accordingly about 2,900 kilometers.

(5) The core reflects and refracts the elastic waves as if it had a clearly marked surface, at which there is a considerable change in density and elastic constants. The data are not in agreement with any hypothesis which calls for a gradual change in composition or properties from core to mantle, taking place through a zone which is a considerable fraction of the radius.

(6) The speed of compressional waves is considerably less within the core than in the material outside.[1] Without further information than is yielded by the elastic waves, it is not possible to say whether this is due to increased density or to decreased incompressibility (K) and decreased rigidity (R).

Other less certain facts yielded by the measurement of the properties of elastic waves are the discontinuities at depths of 1,200, 1,700, and 2,450 kilometers below the surface. Discontinuities near the surface, namely, at 60 and 70 kilometers, are considered in the next paper.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C.

[1] This was illustrated experimentally by an optical analogy, by means of the shadow cast by a solid sphere of glass in air.

THE EARTH'S CRUST AND THE DISCONTINUITY BENEATH IT

L. H. Adams

The Earth is now believed to have a real crust—not in the old sense of a solid layer floating on a liquid interior, but rather in the sense of a thin covering of material radically different in composition from the sphere which it surrounds. It is interesting to recall that only a few decades ago Osmond Fisher argued with convincing and almost flawless logic that the solid crust of the Earth rested on a mobile liquid. But it is now universally admitted that the whole Earth (except possibly near the center), far from having the mobility commonly associated with the word liquid, has a rigidity approaching or exceeding that of steel.

Let us now note the various lines of geophysical evidence which show that the region 50 or 100 kilometers below the surface possesses certain peculiarities.

In the first place, the results of gravity measurements have established the reality of isostatic adjustment. The thickness of the layer in which gravitative stresses are not completely relieved by yielding of the rocks is usually placed at 60 to 100 kilometers. Evidently there is an outer layer which differs in some way from the material below it. In this connection, it is important to observe that the conclusions reached by measurements of gravity have recently been strikingly confirmed by calculations based on the known densities of rocks collected at the surface in various parts of the Earth.

The temperature increases steadily with increasing depth. Now, it is just in this region, 60 to 100 kilometers below the surface, that the temperature approaches closely to the melting point of silicate mixtures corresponding to the ordinary rocks. The fact that at this depth the rocks are so near their melting point would indicate an increased ability to flow, and might have an important bearing on the phenomenon of isostasy.

Perhaps the most direct and definite evidence concerning the crust of the Earth comes from the results of seismic observations. These results, and in particular those for near earthquakes, show us a discontinuity at a depth of about 60 kilometers. At this depth the velocity of the longitudinal vibrations increases rather suddenly from 5.8 to 8.0 km./sec. and on account of the change in elasticity the earthquake waves undergo a marked reflection.

Finally, laboratory measurements on the elastic constants of various rocks have contributed to our knowledge concerning the composition of the Earth's crust and of the material below the crust. By comparing the wave-velocities at various depths with the velocities calculated from

the measured elastic constants of typical rocks, we are able to determine the composition of the material at any given depth. In this way it has been learned that the crust is a shell, almost entirely of granite, resting on material which is uniform and of the composition of peridotite all the way down to the central iron core.

It may be said that the seismic results prove too much. If we accept these results at their full face value, basaltic rocks are removed from the picture. That basalt should occur only in insignificant amounts within the Earth is an idea which will be vigorously opposed by most geologists. Possibly the seismic results are neither sufficiently accurate nor properly interpreted, and further investigation in this field is of the very highest importance.

The various considerations mentioned above—geodetic, thermal, seismic, and elastic—all point to change or discontinuity of some kind at a depth which is less than 100 and more than 50 kilometers. Whether or not the singularities revealed by the different methods pertain to one and the same level is as yet an unsolved problem. All of the data, however, are in accord with the idea of an originally molten Earth, the silicate part of which solidified (crystallized) from the bottom upward, leaving the present crust as a residuum of impurities concentrated by an orderly differentiation of the Earth as a whole.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C.

THE CHEMICAL COMPOSITION OF THE EARTH, OF METEORITES, AND OF THE SUN'S ATMOSPHERE

H. S. WASHINGTON

The preceding speakers have pointed out several of the lines along which we arrive at a knowledge of the constitution of the Earth. In these, and several other, ways we have come to believe, and with a high degree of probability of our belief, that a core of metallic iron, or nickel-iron, occupies the center of the Earth. This metallic core has a radius of about 3,400 kilometers. It changes, by the gradually increasing assumption of silicate material, first into a "lithosporic" shell—one in which silicates (especially olivine and pyroxene) are included sporadically in the metal, and then into a "ferrosporic" shell, in which gradually decreasing amounts of metal occur sporadically in silicate rock. This mixed zone is about 1,400 kilometers thick, and, for purposes of computation, we may assume that the lithosporic and the ferrosporic shells are each 700 kilometers thick. Outside of this is a shell of peridotite—a rock made up of olivine and pyroxene—which is about 1,540 kilometers thick, and above this the "crust" of the Earth, about 60 kilometers thick, the

lower two-thirds being basaltic and the upper one-third being granitic.

The respective volumes and masses of these various shells and of the central metallic core have been calculated. Also, on the assumption that the chemical and mineral composition of the core and of the lithosporic, ferrosporic, and peridotitic shells is that of the average of the corresponding meteorites, and with a fairly safe knowledge of the average composition of the basalts and the general granitic rocks of the "crust," from these data the general chemical composition of the whole Earth has been calculated. The result is given in Table 1.

Table 1. *Chemical Composition of the Earth*

Iron (metal)	31.82	Sulphur	0.64
Nickel (metal)	3.16	Sodium	0.39
Cobalt (metal)	0.23	Chromium	0.20
Oxygen	27.71	Potassium	0.14
Silicon	14.53	Phosphorus	0.11
Magnesium	8.69	Manganese	0.07
Iron (silicate)	7.94	Carbon	0.04
Calcium	2.52	Titanium	0.02
Aluminum	1.79		100.00

These results are admittedly approximate; but, if the assumptions are reasonably correct, they cannot be very far wrong, except that the percentages for sulphur, phosphorus, and carbon are probably too low. It appears that four elements, iron, by far the most abundant, oxygen, silicon, and magnesium, make up 90.7 per cent of the Earth. These, with three others, nickel, calcium, and aluminum, make up 98.2 per cent; and with five others, sulphur, sodium, cobalt, chromium, and potassium, each in amount of less than one per cent, constitute 99.8 per cent of the Earth. Probably phosphorus, to the extent of 0.1 per cent, and carbon and chlorine, to the extent of about 0.05 for both, should be added to the list. It thus appears that the Earth, as a whole, is composed almost exclusively of but 12 or 14 elements, and that the percentage of the 80 or 78 others is almost negligible, as they, altogether, do not constitute very probably more than about 0.1 per cent of the Earth.

These most abundant elements are all of low, but not the lowest, atomic weight and atomic number; the highest atomic weight represented is 59 (cobalt), and the highest atomic number is that of nickel (28). Without going into details, it may be said that there is a serial progression, from the center to the surface, as regards most of these elements, the progression being positive for some and negative for others.

A feature of special interest, bearing on our views as to the derivation of the Earth and the other planets from an original nebula or a primeval, disrupted sun, is the correspondence between the composition of the whole Earth and that of the sun's atmosphere. By spectroscopic methods one may arrive at a roughly approximate idea of the relative abundance of the elements that constitute the atmosphere of the sun. On comparison, it is found that, of the eleven most abundant elements in the Earth, nine (Fe, Si, Mg, Ni, Ca, Al, Na, Co, Cr) are among the eleven most abundant in the sun's atmosphere. Some slight discrepancies are explicable by the differences in physical conditions and by the peculiarities of the spectroscopic observation of certain elements—oxygen, for example.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C.

THE ORIGIN OF THE OCEAN AND THE ATMOSPHERE

W. J. Humphreys

How the Earth acquired an atmosphere and where the oceans came from, have been fascinating problems ever since there were children to ask questions and grown-ups who couldn't answer them. However, experiments of the physicist and observations of the geologist and the astronomer have furnished the warp and the woof with which the mathematician at last has woven a theory that clothes both these Sphinxes in rare and beautiful raiment.

To begin, not truly at the beginning, but as far back as even part-knowledge permits, we believe that all that we call electricity and all that we call matter consist of two things as yet unresolved—the electron and the proton, the negative and the positive electric atoms, or at most, these ultimate charges and their carriers. At any rate, these are the most elementary entities of which there is any fairly definite evidence. We have no knowledge of the origin of either the electron or the proton. They can exist separately, from which we infer that they may have originated differently and in different amounts, the excess diffusing itself to infinite rarity. On the other hand, the equality of their charges suggests a common and simultaneous origin. But, be that as it may, they usually are combined in various equal numbers, thereby forming all the material elements from hydrogen to uranium. Hence, wherever matter occurs in great quantity, as in a star or a planet, one may expect to find all the possible elements in varying proportions, and also such compounds of them as the temperature and other conditions favor. Presumably, therefore, every heavenly object, however nebulous or condensed, has within itself, as certainly as our own sun has, the makings of an atmosphere and an ocean. Evidently, then, when the Earth was pulled out of the

sun by the tidal action of a passing star of much greater mass, there were taken along the hydrogen, oxygen, and nitrogen of the ocean and the air as well as the iron, silicon, aluminum, and other elements of the lithosphere.

The portion of the sun thus torn out by tidal action broke off during this process, if we accept Jeffrey's logic,[1] in separate masses which, owing to expansional and radiational cooling, soon in great measure became liquid. The rest was gases and vapors surrounding these centers, and cosmical dust and debris left throughout the disk of the new-born solar system. In the case of the Earth, it appears that the gravity pull of the liquid globe was quite sufficient to retain water vapor, if such existed, and all the gases of the atmosphere except hydrogen and helium.

After a relatively very short period, only a few thousand years, a more or less stable crust formed, consisting essentially of rock-material, the iron and other heavy elements through the action of gravity having formed the inner core. The surface temperature then rapidly fell to a value comparable to that which seems to have obtained ever since, leading to condensation of most of the water vapor, if it existed in large quantity, and to a well-nigh perfect conservation of all atmospheric gases, including now even hydrogen and helium. But whatever this primordial supply of free air and free water vapor, the crusting of the Earth was accompanied and followed by lava flows and other forms of eruptions all giving off then, as they do now, vast volumes of steam, carbon dioxide, nitrogen, hydrogen, oxygen, and other gases, each of which had been absorbed, occluded, combined, or otherwise taken up by the rocky materials while in their previous gaseous or liquid state. In this way such original gases and initial water as may have existed were rapidly supplemented until an atmosphere substantially as it exists today had accumulated, and great oceans had covered most of the Earth.

Later on, when vegetation had developed chlorophyl-bearing types, the oxygen of the air presumably was greatly increased by their absorption of carbon dioxide and liberation of free oxygen.

Such, in broad and general terms, is the latest theory of the origin of our atmosphere and our oceans, a theory of beautiful texture woven by Mathesis from the many-colored threads of observation and experiment.

U. S. Weather Bureau,
Washington, D. C.

DISCUSSION FOLLOWING SYMPOSIUM

Dr. Bowie. I think that we should go back one step further in trying to account for the presence of oceans. The greatest contribution, in my

[1] Jeffrey's *The Earth*. Cambridge University Press, 1924.

judgment, to the knowledge of why we have oceans was made by Dr. Henry S. Washington when he correlated the analyses of igneous rocks with the elevation of the ground. According to this correlation, there is a very definite relation between the norms derived from the quantitative and qualitative analyses and the general elevation of the Earth's surface surrounding the places where the rocks were found. The larger norms apply to the lower elevations. It seems to me that we have here a clew as to why we have an irregular surface of the Earth with wide basins, which we call oceans, and broad plateaus or highlands called continents. Of course, to explain the ocean with entire satisfaction, we should go back even one step further and try to learn why the heavier elements are present in larger percentages in some portions of the crust than they are in others. I think I am correct in saying that Dr. Washington is planning to attack this problem in the not distant future. In any event, we had an irregular surface of the Earth to start with before the age of rainfall or what is better known as the age of sedimentation.

Dr. Washington. One of the most important outstanding problems in regard to the constitution of the Earth is why there are the great continental masses and the still vaster oceanic basins. The former are composed of compartively light, granitic rocks, while the ocean floors are basaltic, which is in accord with the doctrine of isostasy. But, on the whole, it appears to me that this regional heterogeneity of the crust, complicated by the existence of co-magmatic regions of different chemical composition, is one of the most difficult features that we have to explain in discussing the Earth's constitution.

Dr. Reid. Professor Joly of Trinity College, Dublin, thinks that as the Earth cooled originally it was surrounded by a liquid magma; that the acid rocks separated from this magma and formed the material of the continents, which, being lighter than the remaining basaltic magma, floated in it. When the basaltic layer solidified, its density increased and the continents floated still higher. It must be left to the petrographers to decide if this suggestion of differentiation in the magma will hold.

Dr. Bauer. This question of an iron-core hypothesis of the constitution of the Earth is naturally of great interest to the magnetician. Chamberlin expressed the view that our knowledge of the Earth's interior is to be chiefly gained from seismology and terrestrial magnetism. I may recall that Schuster in his presidential address before the Physical Society of London in 1912 reviewed the various theories with regard to the possible causes of Terrestrial Magnetism. He considered that it would be premature to discard, before further investigation, the hypothesis that an iron core of the Earth may be the cause. As we go into the interior of the Earth the temperature continually increases, and it

has been calculated that at a depth of about twelve miles we would have a temperature at which magnetization could not exist. However, this calculation neglects any possible effect on the critical temperature of magnetization which may be caused by the increased pressure as we penetrate into the interior. Schuster, accordingly, initiated some experiments to find out whether the loss of magnetism due to increased temperature might be offset by increased pressure. The experiments were difficult. They were carried on at the University of Manchester by Mr. F. Whaley. Some years ago I wrote to Dr. Petavel, who had designed the pressure furnace used by Whaley, as to the continuation of these experiments, possibly at the National Physical Laboratory, but he replied that nothing further had been done. Dr. Adams, of the Geophysical Laboratory, and Mr. Green, of the Department of Terrestrial Magnetism, are now investigating the question as to the effect of pressure on the critical temperature of magnetization. This is one line of inquiry which is of particular interest to us in connection with this symposium. Another line that I may mention is the result of an analysis which I made of the Earth's magnetic field based on actual observations. Let us take the simplest possible case of magnetization of the Earth; namely, the portion of the Earth's magnetic field which is symmetrical about the axis of rotation. The magnetic poles would then coincide with the geographic poles. If the Earth consisted entirely of iron, we might have a uniformly magnetized Earth and the intensity of magnetization for any point on a parallel of latitude could then be represented by the radius of a sphere. In fact, the figure which would represent the intensity of magnetization at all points would be a sphere. If, however, we take the actual observations, as based on the extensive work of the *Galilee* and the *Carnegie* on the oceans and of the various expeditions on land, such a simple representative figure of magnetization is not obtained. Instead, we get a pear-shaped figure, showing some relationship to the distribution of land and water. We thus have evidences of lack of uniformity of magnetization even for the simplest possible case. Furthermore, the pear-shaped figure would have a number of humps in it for different regions of the Earth. It is thus possible that facts derived from a critical study of the Earth's magnetism may assist in obtaining some information with regard to the constitution of the Earth.

Professor Macelwane. I should like to disclaim the responsibility for final pronouncements as to the possibility of transverse waves passing through the core of the Earth. We have observed groups that look like transverse core waves appearing on successive records in an earthquake, but the evidence is not conclusive enough for any definite statement. I think the problem still remains open and that there are two possibilities

in regard to it. Some calculations we made recently seem to indicate that only a slight fraction of the incident wave energy could enter a rigid core as a transverse vibration and that only a small part of this can emerge in transverse form. Suppose we find eventually that no transverse waves are observed, it may be that the core will not transmit them. But it may also be that they are not absent, but that their energy is too slight to allow them to appear in the midst of other waves.

Dr. Wright. Referring to the question regarding the discontinuities of different layers in the Earth: When light is reflected from a glass surface, there is evidence that light penetrates a certain distance. When the waves from a sonic depth finder strike an oozy bottom, I understand there is a different kind of reflection from that produced by a solid bottom. A number of sound waves may be easily included within the depth of the layer of the ooze. In connection with earthquake waves, the question is, how abrupt is this discontinuity? Is it measured in kilometers or not? How sharp will this reflection be for the transverse waves?

Dr. Adams. This is one of the most important questions in seismology. It should be possible to determine how sharp it is. Possibly the transition zone extends over several tens of kilometers. In general a discontinuity means a zone of transition of the same order of magnitude as one wave length, and if this zone is even a few kilometers in extent it should not be called a discontinuity.

Professor Willis. It has been my privilege to enjoy the discussions on seismology with the physical seismologists and in one or two instances to compare their conclusions with those of the geologist. When my colleagues speak of waves which have been transmitted from a distant focus and seek to find the exact center of that focus, the distance is so great as compared with the area of the origin that they can speak of that area as a point. I have, from the geologist's point of view, an impression that the center is often square miles in extent and that we are dealing sometimes not with a single movement, but with several closely allied movements. A study of the earthquakes in southern California from 1915-1925 has led me to think that some of the heavier earthquakes have each had several centers located on faults some miles apart.

In my work in Chile on the great earthquake of November 10, 1922, I found that the higher intensities were located on many faults, a fact which has been observed in Germany and elsewhere. That may have its bearing upon this question of a zone of discontinuity or a sharp line, since the origin is involved in the study of the path of the wave. I would suggest that the Earth is extremely varied in its phenomena. Judging from what geology teaches, the dynamic histories of different coasts do

not match each other. Each ocean basin is a dynamic center distinct from any other. I should like to plead for the application of the method of multiple hypotheses, using these valuable results that have come out of the work of some of the men who spoke today, together with geological and other related data.

Dr. Bowie. With regard to the thickness of the crust from the geodetic standpoint, I should say that any value derived from geodetic data is merely a mathematical expression. We have to assume something in our isostatic investigations in regard to the distribution or depth to which heterogeneous densities in the outer portion of the Earth extend. We assume, in these isostatic investigations, a uniform depth of compensation and then proceed to determine what the value of that depth is. Although we can eliminate the gravity and deflection of the vertical anomalies by using a depth of 50 miles almost as completely as by the use of the most probable depth of 60 miles, yet the 60-mile depth is of the order of magnitude of the thickness of the Earth's crust. There is undoubtedly a limit to the depth to which material extends that can maintain its form against gravitational stresses. If this were not true, then the continents would overflow the oceans and the heavier material beneath the oceans would underflow the continents. It is probable that, later on, as data accumulate and investigations are extended, the depth of the crust as computed from seismological data may be brought more closely into harmony with the depth as computed from the geodetic data. There is really not so very much difference between the 60 kilometers of the seismologist and the 96 kilometers of the geodesist.

It should be clearly borne in mind that the geodesist is not eliminating the gravity anomalies. He is attempting to explain them, and by their explanation he hopes to reach some knowledge of geological structure that is not evident from investigations along other lines.

Dr. Reid. Whether this central core transmits transverse vibrations or not, I believe there has been some objection on the score of stability to a liquid center of the Earth.

Prof. Macelwane. The point raised by Professor Willis seems to me to be well answered by the computations made by Dr. Reid some years ago and published in the Bulletin of the Seismological Society of America as to the effect of an extended fault movement in an earthquake on the character of the records of seismographs at greater distances. The conclusion reached was that at any distant place the beginning of a group is determined by waves from that point at which the break occurs first on the fault plane, provided the first movement is sufficiently strong to reach all the stations.

Dr. Washington. With regard to the magnetism of the Earth, one

point is apparently not appreciated. An argument constantly brought up against the magnetism of the Earth being due to a central core of metallic iron, is that iron loses its magnetism at a temperature of about 785°. This is true of *pure* iron and under atmospheric pressure. But, thus far, we know nothing about the effect of high pressure on the magnetic properties of iron at high temperatures. Also, from analogy with meteorites, we are justified in believing that the central core is of nickel-iron alloy, and we know that the magnetic properties of the nickel-iron alloys differ much from those of pure iron. The addition of less than one per cent of carbon to pure iron will change it, on magnetization, from a temporary to a permanent magnet. Furthermore, there are alloys of such nonmagnetic metals as aluminum, copper, and manganese, that are quite strongly magnetic, and the addition of a quarter of one per cent of manganese to bismuth will make this magnetic. We must, therefore, be cautious in our generalizations from the study of the magnetism of pure iron.

Dr. Reid. The materials of the Earth's crust are of quite different densities in different parts of the Earth's surface; but there are two things, I think, which show the general spherical symmetry of the Earth. The first is the almost perfect conformity of the Earth's surface to an ellipsoid of revolution; the second is the uniformity of the velocity of earthquake waves in different parts of the Earth. The waves from the California earthquake of 1906 arrived at stations equidistant from the origin at closely the same times, independently of the direction or whether their paths were under the ocean or under the continents.

In a recent paper on the characteristics of the interior of the Earth Professor Wiechert is led, through the study of earthquake waves, to the conclusion that the Earth is made up of three layers: A central core of nickel and iron, an outer layer of stony material, and an intermediate layer of a mixture of these two. This corresponds with the conclusions of Williamson and Adams, except that Wiechert's intermediate layer is more uniform. He finds that there is not a great deal of compression, but that the density is largely controlled by the material. He has calculated the radii of these layers to satisfy the astronomical conditions. He also mentions the other layers which Dr. Sosman spoke of, but thinks them rather unimportant.

Dr. Sosman. With regard to the general features of the interior, we may draw a parallel with the experience of the chemists. To the early chemist, silica was an undecomposable substance, ranking with the metals as a chemical *element.* Then it was found to consist of silicon and oxygen, and became a chemical *compound.* Now we know that silicon itself

is not a single kind of atom but consists of three *isotopes*. Yet it remains true that silica is a chemical substance, and silicon is still a chemical element. So with the Earth's interior, the general features as we now have them are perhaps essentially correct, though subject to minor modifications. In their general form I think they will stand.

Prof. Macelwane. A point not worked out is the question of a possible heterogeneity down under the Pacific. Neumann and Service are obtaining results in this connection which are surprising. Waves traversing layers deep down under the Pacific and coming up at stations like Honolulu seem to differ in their travel times from those which follow equal subcontinental paths by an amount which is beyond the limits of errors of observation. That seems to indicate a problem into which we ought to look much more fully.

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SECTION OF GEODESY

(Washington, D. C., April 29, 1926)

LOWER ST. LAWRENCE RIVER EARTHQUAKE OF 1925 AND COOPERATIVE INVESTIGATION BY THE DOMINION OBSERVATORY AND THE GEODETIC SURVEY OF CANADA

NOEL J. OGILVIE

In 1662 the French settlement along the St. Lawrence River (Fig. 1) was faced with a liquor problem which broke the heart of Bishop Laval, who at that time was head of the Roman Catholic Church in Canada. Excommunication and every means within his power were used to prohibit the sale and use of liquor, but all to no avail, and as a last resource he sailed for old France, hoping to secure assistance from the home government. Hardly had he left the shores of New France when it was believed by many a Mightier Agency had interfered, for, in the year 1663, the St. Lawrence valley was rocked by an earthquake which, if we are to believe history, moved mountains, changed river courses, and, to use the words of the native Indians, "the very trees in the forest danced as though they were intoxicated."

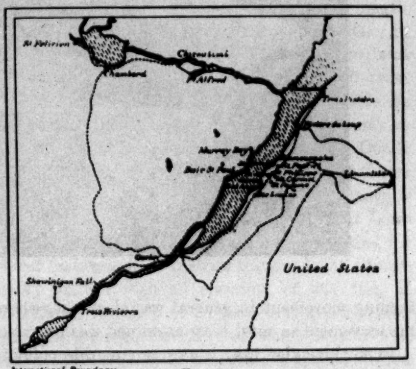

FIG. 1

The earthquake which I wish to refer to particularly today is that which occurred on the evening of February 28, 1925. Coincident with the shock a loud roar was heard in the St. Lawrence valley, while at points as far west as Ottawa there was a noise similar to the passing of a heavy truck upon the pavement; the shock itself lasted only a few seconds, but tremors were felt for the following two weeks. While attending a hockey game in our auditorium at Ottawa, a building which is built of steel, concrete, and brick, I felt the shock. The greatest damage was done in the neighborhood of St. Pacome, Riviere Ouelle,

Baie St. Paul, and Shawinigan Falls, where occasional stone buildings were cracked or partly wrecked and chimneys tottered over.

The effect upon tombstones was peculiar in that some were lifted vertically several inches and then fell on their sides, while others were left standing but turned in azimuth (Fig. 2); on the north shore the

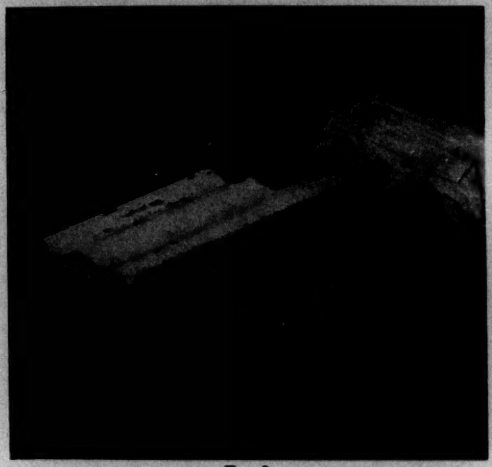

FIG. 2

turning movement in general was clockwise, whereas on the south shore the movement in most cases examined was contra-clockwise.

In a particular case where two marble columns rested on a smooth stone base and were capped by a single smooth stone cap, the position of the base and cap remained unchanged after the quake, but the two columns were turned approximately 45 degrees in azimuth (Fig. 3).

Numerous cracks appeared in the earth's crust between Riviere Ouelle and Riviere du Loup on the south shore, but in no case did they exceed one hundred and fifty feet in length, three inches in width, or twenty feet in depth (Fig. 4); also cracks in the snow mantle were reported from points as far east as Kamouraska. Contrary to paper reports at the time of the quake, it has been found no harm was done to any person physically, except in a few cases where minor cuts were caused by falling glass.

In these days of specialization any one branch of Science is handicapped unless it can have the maximum of cooperation from several other specialists—and in the study under observation, the value of the

conclusions of a seismologist are limited unless he has cooperation from Geodetic and Geological surveys; that is, he must have reliable horizontal and vertical control by a Geodetic survey and a study of the rock and soil formation from the Geologist. I might say that cooperation has always been the keynote in our relations with the Dominion Observatory and we were very glad to be of service to them in the spring of 1925. We had a system of primary triangulation straddling the St. Lawrence and also a line of precise levels along the south shore—if funds had been available we would both have reoccupied our triangulation stations and relevelled the precise level line, but it was felt that the maximum amount of information consistent with funds at our disposal could be obtained in going over the precise level line. Accordingly, following a request from the Observatory, an engineer and precise leveling party relevelled the 114 miles between Riviere du Loup and Levis. It was believed that any vertical displacement due to the quake would show up in this length of line, since the greatest shock was felt between these two points. In figure number five, the straight line represents the 1915 elevations, and points on the irregular line represent the rise or drop in 1925 from 1915 calculations. Let us examine the 1925 curve; between Riviere du Loup and Riviere Ouelle any change in elevation of bench marks may be accounted for by frost action or instrumental errors; from Riviere Ouelle to Montmagny there is a gradually increasing drop and at the latter place this drop in elevation amounts to 0.37 foot; from Montmagny southwestward there is a gradual pick-up in the difference, and at Levis the closure is shown to be approximately 0.1 foot. Let us examine for a moment the topographical features of the district traversed: At Riviere du Loup we have a rocky plateau with an elevation of 300 feet, at Riviere Ouelle a trough with an elevation of 35 feet, next a fairly level plain 60 miles in length, the average elevation of which is 100 feet, and lastly a plateau behind Levis with solid limestone a few feet below the ground surface and at an elevation of approximately 325 feet above sea level. In passing, I should like to draw your attention to the fact that the Dominion Observatory, in their preliminary survey of the district immediately after the quake, came to the conclusion that the fault line along which the disturbance centered, made its entry to the south shore of the St. Lawrence River at the Riviere Ouelle trough. In figure number six, the bench marks are represented at their actual elevation in 1915, that is the full black line. Heretofore we have considered the 1925 relevelling as it was actually run in the field from Riviere du Loup southwesterly. We are equally at liberty to represent it as run from Levis northeasterly, and if we do this the dotted line here shows the shift in the bench marks in the ten-year interval from 1915 to 1925. Furthermore, we now see the two curves to intersect near St. Pacome, showing

FIG. 3

FIG. 4

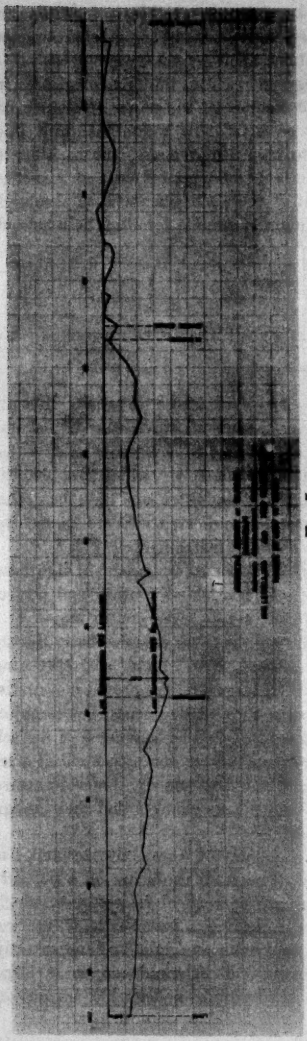

FIG. 5

Geodetic Survey of Canada
— Precise Levelling —
Showing Comparison Between
1919 Levelling — 1925 Relevelling

a rise in elevation since 1915 for bench marks northeast of St. Pacome and a drop to the southwest. Thus precise levelling has given a complete substantiation of the field observations made by the seismologist.

In conclusion, from the seismograph records, the seismologist calculates the approximate direction and distance of the center of disturbance from the instrument station, the geologist tells where the fault lines exist and where we may expect to find a movement; but in order to definitely determine that there has been a horizontal shift or a vertical displacement and the actual extent of these movements, it is absolutely necessary that Geodetic triangulation and precise levelling both precede and follow an earthquake.

Geodetic Survey of Canada,
Ottawa, Canada

DESIGN OF A PRECISE THEODOLITE

D. L. Parkhurst

The Coast and Geodetic Survey has experienced so much difficulty in the past few years in obtaining satisfactory first-order theodolites, and by this I mean instruments which can be read to one second of arc, that we have decided to design an instrument ourselves which will embody the various desirable features of existing theodolites, and also such other characteristics as our field experience has indicated will aid in making a more rugged, portable, and easily operated instrument.

Briefly, the essentials of a theodolite such as we need are lightness, ruggedness, a perfectly graduated circle, frictionless centers, and perfect optical qualities. Perfection, of course, can only be approximated.

The instrument designed and built by the Coast and Geodetic Survey about 25 years ago has a long telescope, large circle, and spreading microscopes. This theodolite, despite its large size, has proved more satisfactory in many ways than the more modern instruments, but is objectionable because of its bulk and long telescope, and also because of its lack of a vertical circle. This lack prevents its use for astronomical purposes in high latitudes. The axes of this instrument, however, are so frictionless and so little affected by temperature changes that their design has been followed in the new theodolite.

The theodolite built by the Kern Company of Aarau, Switzerland, has a number of very valuable features. The graduations are on a flat surface, not on a cone, permitting the use of vertical microscopes, which reduce the spread. For convenience in reading, a prism is built into the eye-piece so that the circle may be read from an angle, and not directly downward. The telescope is short and well balanced and has a large objective so that plenty of light is admitted—a desirable feature in

night surveying. It is internal focusing, which renders it practically dust proof and also shortens the length. The alidade center, however,

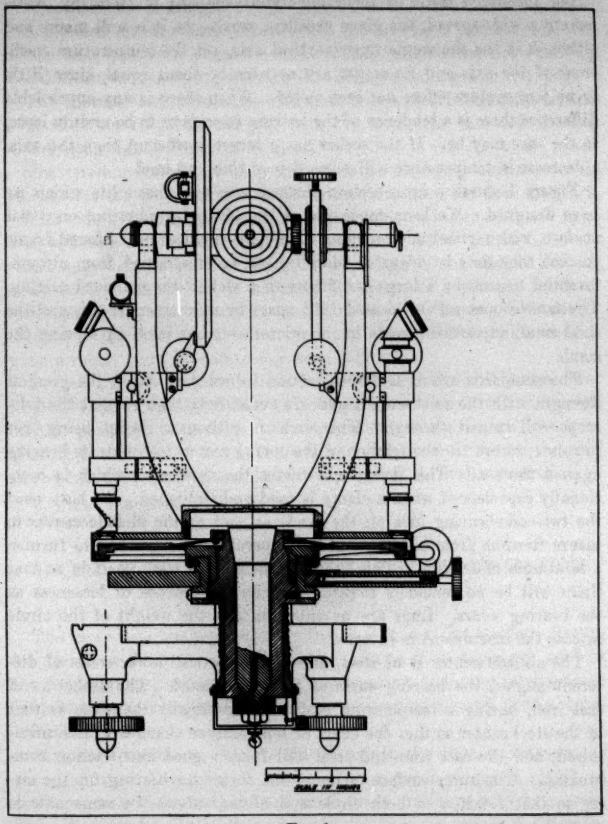

FIG. 1

Cross-section of U. S. Coast and Geodetic Survey 9-inch precision theodolite.

is in the form of a single long taper with a small thrust-bearing at the bottom. We have found it to be considerably affected by temperature changes, with resultant binding. The changes are so noticeable that it

has been a most unpopular instrument with the observers, as it requires frequent adjustment.

The theodolite made by the Hildebrand Company of Germany, while having a wide spread, has given excellent results, as it is well made, and although it has the single taper vertical axis, yet the temperature coefficient of the axis and its socket are apparently about equal, since little or no temperature effect has been noted. When there is any appreciable difference there is a tendency of the bearing to seize or to be unduly loose, as the case may be. If the socket has a larger coefficient than the axis, a decrease in temperature will cause it to shrink and bind.

Figure 1 shows a cross-section through the new theodolite which we have designed. We have made use of the idea of graduating on a flat surface, with vertical microscopes. These are mounted on a hinged frame so that they may be adjusted radially, but are restrained from circumferential motion by a large ear fitting in a slot in the standard casting. The microscopes will be located 180° apart by mechanical means and the final small adjustment made in the micrometer box itself by moving the comb.

The standards are of L-shaped section in order to obtain the greatest strength with the least weight and are sufficiently high so that the telescope will transit through. The circle is without a clamp, being free to rotate, except for the friction of the spring nut which holds its bearing against the seat. This design eliminates the movement which is occasionally experienced when a clamp is used and tightened. We have used the two-cone-bearing idea on the circle as well as the alidade center to insure freedom from binding due to temperature changes and to furnish a minimum of friction. This type of bearing will wear itself in so that there will be no tendency towards eccentricity because of looseness as the bearing wears. Lugs are provided to take the weight of the circle in case the instrument is inverted.

The alidade center is of steel, and has upper and lower cones of different angles, the bearing surfaces being hardened. The socket is of cast iron, having a temperature coefficient practically the same as that of the steel center so that the effect of temperature changes will be minimized, and the cast iron and steel will form a good anti-friction combination. The outer surface of the socket forms the bearing for the circle so that rotation of both circle and alidade about the same axis is assured.

The alidade axis is pierced with a hole large enough to permit the passage of an insulated wire, through which to bring current for illumination of the cross wires and microscopes. This, you will note, is brought out to an insulated ring. A brush is mounted on a "U"-shaped bridge attached to the tribrach so that the slip ring is exposed and may readily

be cleaned without in any way disturbing the adjustment of the instrument.

The conductor is brought out through the side of the bearing in order that the mechanical centers, upon which the bearing is constructed, will not be destroyed, as is often the case. When these centers are removed, it is difficult to true up the bearing if it becomes damaged in any way.

The tribrach is of aluminum, with arms hollowed out for lightness, and with a lifting ring cast integral with the arms, the cast-iron bearing socket being tightly threaded in place.

The leveling screws are long and of large diameter, and a cover is placed over the threaded hole in the tribrach to keep out dust and dirt.

This view gives a better idea of how the completed instrument will look. You will note that the standards are slender and rather narrow.

All improvement has been made in the design of the alidade tangent screw in that the motion is imparted by means of a plunger which is restrained from rotation, so that its motion is purely linear. This design eliminates the irregularity of motion and lifting effect which obtains when a rotary point is eccentric or worn obliquely.

The advantages that we believe this new theodolite will possess are: Lightness (it is estimated that the complete instrument will not weigh over 40 pounds); ruggedness; accuracy; easy running centers free from binding due to temperature changes; an instrument which can be used in any latitude; compactness, by virtue of use of vertical microscopes.

U. S. Coast and Geodetic Survey,
Washington, D. C.

RECENT WORK IN GEODETIC TAPE STANDARDIZATION

L. V. JUDSON

The invar base-line tapes used by the U. S. Coast and Geodetic Survey are tested at the Bureau of Standards. Since these tapes are used in the fundamental geodetic surveys of this country, including international boundary lines, it is essential that every precaution be used in the standardization.

It is now possible to measure the change in the distance between the end graduation lines of such a tape when a small weight is placed on the tape, even if the weight is as small as an ordinary wire paper clip. This effect can be calculated mathematically from the weight of the paper clip and there is agreement between the observations and the calculations to about the one fifty-millionth part of the total length of the tape.

Tests on the hardness of different portions of tapes are now being made on a group of tapes, as a preliminary investigation indicated that certain variations in the uniformity of the material which might render

the tape unsuitable for the highest precision could be detected by changes in hardness.

A compilation of data on all the base-line tapes which have been tested at the Bureau in the last twenty years is about completed. It is hoped that these data, together with similar data being assembled in other countries, will be of service in securing the highest possible accuracy in the standardization and use of base-line tapes.

Bureau of Standards,
U. S. Department of Commerce,
Washington, D. C.

FIRST-ORDER LEVELING

H. G. Avers

The general plan of extending the first-order level net of the United States has been to locate the lines in such a way that eventually no place in the country will be more than fifty miles from a standard bench mark.

In prosecution of this plan, 50,000 miles of first-order levels have been run by the U. S. Coast and Geodetic Survey, the U. S. Geological Survey, the Corps of Engineers, U. S. Army, the U. S. Lake Survey, the Mississippi and Missouri River Commissions, and a number of the leading railroads. The work enters every State of the union but one—Delaware—and forms over one hundred circuits.

During the past year lines were run in South Dakota, Colorado, and California, but only one line will be mentioned in particular at this time.

At the request of the Seismological Committee of the Carnegie Institution, a line of first-order levels was started at the 8,400-foot contour on the slope of Mt. Whitney, California. The work was extended downward across Owens Valley and up the slope of the Inyo Mountains to the 5,000-foot contour. An attempt was made to carry the line to the top of Mt. Whitney, but the work had to be abandoned because the trail leading to the summit was made impassable by rock slides. By rerunning this line at some time in the future it will be possible to determine if there has been any relative movement between the valley floor and the mountain masses.

Representatives of the Geodetic Survey of Canada and of the U. S. Coast and Geodetic Survey recently held a conference at Ottawa, Canada, for the purpose of discussing the problems affecting the first-order level nets of the two countries. The greatest need at present is the adoption of common elevations for the junction points. The level nets have fifteen junction points distributed along the international boundary, and their elevations, as determined by each country, differ from a small fraction

of a foot to over a foot in some cases. This condition is causing great inconvenience to engineers and surveyors who have to use the elevations, and no little embarrassment to the International Boundary Commission who desire to publish the elevations.

The condition at Rouses Point, New York, is outstanding. The elevation of one of the bench marks at that place was used as the basis for the elevations of all the leveling in eastern Canada. In recent years a number of new level lines were run into Rouses Point, with the result that there is now an extreme difference of 1.3 feet in the various determinations of the elevation which, if the present elevation were held, would have to be taken up by the new leveling. This closure is much too large for the short lines of leveling involved. The leveling to the south and west of Rouses Point has been revised by the Coast and Geodetic Survey and it is believed to be free from error.

It was thought possible to relieve the condition around Rouses Point by adjusting the eastern portion of the Canadian net with the United States leveling in the New England States and in northern New York. An adjustment of this combined work was made by the Geodetic Survey of Canada about a year ago, but the results were not satisfactory as the corrections were far in excess of the average usually applied to this class of leveling.

At the junction points west of Lake Superior, along the 49th parallel of latitude, the elevation differences are on the average about one foot. This is the region where the International Boundary Commission is especially interested and where the need for common elevations is immediate. In this region it was decided to distribute the closures on the tie lines between the two nets. It is believed that the resulting elevations for the boundary points will agree within a very small fraction of a foot with the theoretically best elevations obtained from any latter adjustment.

Of course, the best way to bring about an accord in elevations along the boundary would be to make an adjustment of the combined nets. Plans are now in preparation to do this eventually, but it is believed best to run some additional leveling before taking up the work in order to provide sufficient strength to hold the elevations for an indefinite period.

U. S. Coast and Geodetic Survey,
Washington, D. C.

THE READJUSTMENT OF THE FIRST-ORDER TRIANGULATION IN THE WESTERN HALF OF THE UNITED STATES

O. S. Adams

At the meeting of the Section of Geodesy held last April, a report was given of the general plan for the readjustment of the first-order

triangulation in the western part of the United States. This plan was conceived by Major Bowie and formulated by him in a general way early in 1924. We shall now give some account of the practical application of this Bowie method to the extensive scheme of triangulation west of the 98th meridian, inclusive of the arc along this meridian.

The first step in the general scheme is to adjust a figure at the junction of two arcs, so that a length and azimuth of a line may be determined that is to be held fixed in the adjustment of the section ending with this line. In the ideal junction figure, a measured base should be found and an observed Laplace azimuth. In some cases, where such conditions are found, the junction figure may consist of a couple of quadrilaterals; in other cases, a more extensive figure has to be used, because of the rather involved figures in the triangulation.

When a measured base or Laplace azimuth is not found in the figure that must serve for a junction, it becomes necessary to adopt a length or azimuth, or both if neither is found in the figure, to serve as control in the adjustment of this part. If a length is needed in the figure, the length of some convenient line is computed from the various adjacent measured bases in the adjoining sections and then a weighted mean of these various lengths is adopted as the length for control in the junction figure. In general, the various computed lengths are weighted inversely as the strength of the figures through which the computations are carried. If the azimuth has to be determined in the figure, the necessary procedure is somewhat similar. The azimuth of some line is computed from the nearest Laplace azimuths in the adjoining sections, and a mean of these various values, weighted inversely as the number of angles used in the computation of the given value, is taken as the controlling azimuth in the junction figure.

After the junction figures are adjusted with fixed lengths and azimuths, the various sections between these arc intersections are adjusted, holding all measured lengths and Laplace azimuths, as also the length and azimuth of the line fixed in the junction figure. Since no conditions are introduced for the closure of loops, there will be outstanding discrepancies of this kind wherever two sections meet in which the geographic positions are computed by different routes. It will then be necessary to apportion these discrepancies among the various sections, so that no undue amount is given to any section to be absorbed by closure conditions. This end can be accomplished by apportioning the closures between the sections with the weight of each section being taken inversely to its length. This amounts to an apportionment of the discrepancies just as discrepancies in a level net of the first order are distributed. By one set of equations the latitude discrepancies are apportioned, and by another independent set the longitude discrepancies are distributed to the various arcs.

At present, about three-fourths of the preliminary adjustment work has been completed and several loop discrepancies have been computed. These discrepancies vary from fifteen feet to thirty-six feet, depending on the size of the loop, but in no case is the discrepancy as much as one part in 150,000 of the length of the loop.

To complete the general scheme, two short arcs have to be observed during the summer of this year. A short section of the Canadian-United States boundary in the northwestern part of the State of Washington has to be completed and an arc extending from Santa Barbara Channel, in California, across the Sierras, to join an arc in Nevada, has to be observed. We expect to be able to determine the most probable positions of the junction points by the end of this year. After that, the various sections can be adjusted to hold these fixed positions in the junction figures.

U. S. Coast and Geodetic Survey,
Washington, D. C.

PRELIMINARY REPORT ON THE USE OF A TUNING FORK IN GRAVITY MEASUREMENTS

PAUL R. HEYL

Abstract.—If it were possible to use a tuning fork as a standard of time, the process of making gravity observations would be much quickened. Two causes of variability in the tuning fork are to be considered: temperature and amplitude. Temperature can be controlled, or at least allowed for, more readily than amplitude can.

Forks of various materials have been studied, and it has been found that magnesium appears to be a promising material.

In order to follow up this question, it is necessary to push the rating of a fork much farther than has been the customary practice.

Bureau of Standards,
U. S. Department of Commerce.
Washington, D. C.

A METHOD OF COMPARING THE FREQUENCIES OF A PENDULUM AND A TUNING FORK

PHILIP P. QUAYLE

Abstract.—This paper describes a method of obtaining a permanent record of the vibrations of a tuning fork against a free pendulum. The apparatus consists of a Coast and Geodetic Survey quarter-second pendulum fitted with special knife edges which are illuminated by a 400-watt projection lamp. The flashes thus produced fall upon a potassium hy-

droxide photo-electric cell. The few micro-amperes of cell current are amplified by means of a suitable resistance coupled amplifier in order to operate an oscillograph element. This element records its motion on the film of a special high speed camera, giving a record 40 feet in length.

With the apparatus in its crudest form, the probable error of the mean of the fork vibration over four successive seconds due to whatever causes does not greatly exceed one part in 50,000.

With this method it is not necessary to have an approximate calibration of the fork or, in fact, to know anything about it.

Bureau of Standards,
U. S. Department of Commerce,
Washington, D. C.

USE OF THE GRAVITY PENDULUM AS A TIMEPIECE FOR LONGITUDE DETERMINATIONS

E. J. Brown

Longitude determinations of a precise nature are made by measuring the difference in longitude between a point of unknown position and a point whose position has been very accurately determined. The longitude difference can as well be expressed as a time difference and is, in fact, so measured, and it is evident that the accuracy with which the time difference is known is the sole factor determining the accuracy of the results of the longitude observations.

The modern method of measuring differences in longitude is to compare time as obtained by local star observations with a radio time-signal sent at a known time from a point of known longitude.

In the actual observations, a ship's chronometer is used as a timepiece and a clock error is determined by star observations both before and after the reception of the radio signal. Using the two errors thus found, a clock rate can be computed and an interpolation made for the clock error at the instant of reception of the time signal. It is evident that any error in the value of the clock rate determined will directly affect the longitude results. To keep this error within desirable limits, it is necessary to make the star observations in as short a time as possible in order that the chronometer need not be depended on to carry time for any long interval. The ordinary ship's chronometer, when operating under wide ranges of temperature, as is usually the case in the field, will not carry time with sufficient accuracy for more than an hour. If, then, it becomes necessary to make star observations several hours before or after the radio signal is received, it is obvious that a more accurate timepiece must be used.

During the meeting of the Section of Geodesy of the International Geodetic and Geophysical Union at Madrid, in 1924, this very problem confronted the committee drafting plans for a proposed world-girdling longitude survey. This survey, which is to take place in October and November of this year, necessitates the reception of time signals from at least two different stations, with a probability of as much as five hours intervening between the signals. The committee discussed the question of timepieces at some length and Major Bowie, who was one of the committee members, suggested the use of the gravity pendulum. Later consideration of the suggestion seemed to indicate that it was a very good one, and at present experiments in adapting the gravity pendulum for use as a timepiece are being carried on.

The standard gravity pendulums are of the Von Sterneck type, a half-second, quarter-meter pendulum. The pendulum swings free on agate bearings in an air-tight receiver with the pressure reduced to about 60 mm. So little friction is offered to the movement of the pendulum that when started with a double amplitude of 8 mm. it will have a double amplitude of 2 mm. or more at the end of a 12-hour swing. Mirrors mounted on the pendulum head and support enable the pendulum oscillations to be counted by means of the flash-coincidence method, using two ships chronometers as timepieces. The chronometers are rated by comparison with radio time-signals or star observations.

The present method of gravity determination gives the period of the pendulum to a millionth of a second. This means that the error due to the pendulum in carrying time over a 3-hour period would be of the order of .002 or .003 second. A ship's chronometer may vary as much as .05 second in the same length of time. This comparison of errors shows the pendulum to be far superior to the chronometer as a timepiece, and its adaptation for use in the longitude observations will greatly increase the accuracy of the determinations as well as remove some of the restrictions in regard to the time at which star observations may be made. The elimination of the necessity for making the star observations so near to the time of reception of the time signals is especially desirable. Clouds will often obscure the stars for two or three hours and if the time signal comes during this period the night's work is lost. During the past field season time signals were sent from Annapolis at noon and 10 p. m. It was necessary, of course, to use the night signal in connection with the longitude observations. Atmospheric disturbances during a period of about two months made recording of the night signals so difficult that many of them were missed. The day signals could usually be recorded with ease during that period, and had it been possible to carry time from the noon signal until dark the observations could

have been made without the use of the night signal, thereby saving a great deal of time.

In adopting the pendulum for use in the longitude work no attempt is being made to do away with the chronometer altogether, and to use the pendulum as an absolute timepiece. It is proposed, rather, to use the pendulum as a means of keeping a very accurate check on the chronometer rate. This could be accomplished by making comparisons between the chronometer and the pendulum by the coincidence method, using the gravity flash apparatus. The flash apparatus, however, has proved to be somewhat faulty in operation, owing to the varying value of the time lags caused by friction of the moving parts, and it is believed that a photographic method of recording the coincidences will give greater accuracy and will also have the advantage of leaving a permanent mechanical record.

The apparatus being constructed will afford a means of tracing the pendulum oscillations on slowly moving film or photostatic paper. By means of a shutter in the clock circuit a break is made in the record at each second break of the chronometer. The point of coincidence can be taken at the extremity of the swing and there should be no trouble in picking it to the nearest second. The half-second pendulums lose a beat on a sidereal chronometer about once in five minutes, consequently an error of one second in picking the coincidence will cause an error in the comparison of but 1/300 second. By making comparisons at frequent intervals a very accurate check will be had on the clock rate and the longitude results will be but slightly influenced by the quality of the chronometer. The probable error in determining a time interval, even of several hours, should be little greater than .01 second.

The use of the free swinging pendulum in connection with the longitude observations will not be its first adaptation to other than gravity work. The Bureau of Standards is using the gravity pendulum as a standard timepiece for testing the qualities of tuning forks, and Professor Michelson is using the pendulum in connection with his work in determining the velocity of light. The results obtained from the pendulum in these experiments have been very good and have demonstrated the effectiveness of the apparatus in keeping time over short intervals.

U. S. Coast and Geodetic Survey,
Washington, D. C.

RECENT DETERMINATIONS OF GRAVITY AT SEA

C. H. Swick

At a previous meeting of this Section, I told you very briefly about some gravity determinations at sea made by Dr. Meinesz, of Holland,

Engineer to the Dutch Geodetic Commission. You remember he used an ordinary Stückrath pendulum apparatus, but made his observations in a submerged submarine and recorded the oscillations of the pendulums photographically. In the summer of 1923, on a trip from Holland to Java through the Mediterranean Sea and the Suez Canal, Dr. Meinesz made about thirty gravity determinations at sea with an accuracy much greater than had ever before been attained at sea.

Recently he has completed another series of sea determinations on a trip from Holland to Port Said, Egypt, over a part of practically the same route followed on the first trip. In the 1923 work Dr. Meinesz found large positive anomalies in certain deep parts of the Mediterranean Sea, and he was anxious to make additional observations over these areas both to test the accuracy of his first determinations and also to obtain additional information in the critical areas. Owing to the international character and value of this work and in response to the urgent request of Dr. Meinesz, the Director of the Coast and Geodetic Survey has promised that the isostatic reductions of these new determinations, as was done for the first series, will be made by mathematicians of the Coast and Geodetic Survey.

Another very important object of these recent determinations was to test out thoroughly a new type of gravity apparatus recently perfected by Dr. Meinesz.

The old Stückrath apparatus, as you will remember, has four pendulums and these oscillate in two pairs of parallel vertical planes, the two pairs of planes being at right angles to each other. In using this apparatus on his first trip, Dr. Meinesz swung all four of these pendulums simultaneously and obtained an independent photographic record of the oscillations of each. By combining the records of each pair of pendulums swinging in parallel planes he was able to compute the period of a hypothetical pendulum, which period was free from any effect of the horizontal acceleration of the ship. The computation of this hypothetical pendulum was a very laborious process which consumed a great deal of time and required almost unlimited patience.

The new apparatus designed by Dr. Meinesz has only three principal pendulums instead of four and these all swing in the same plane, perpendicular to the longitudinal axis of the ship. It has a very ingenious arrangement of mirrors, by means of which the beam of light used in making the photographic record is reflected from the middle one of the three pendulums onto each of the two outside pendulums before it reaches the recording film. In this manner there is obtained directly on the record, and with no computation required, a combination of the oscillations of the middle pendulum with the oscillations of each of the other two, or what might be termed their relative oscillations. The record.

therefore, shows the oscillations of two hypothetical pendulums, and these are free from the effect of any horizontal acceleration of the ship.

In addition to the three principal pendulums just mentioned, the apparatus includes also two shorter auxiliary pendulums, both heavily damped. One of these measures the deviation from the vertical of the plane of oscillation of the principal pendulums or, in other words, the end-wise tilt of the knife edges on which the pendulums swing, which should be kept within certain prescribed limits. The other auxiliary pendulum measures the amplitude of oscillation of the middle one of the three principal pendulums by recording the angle between the axis of this pendulum and that of the damped one. This record is used in computing the correction for amplitude of oscillation to be applied to the final results.

Very accurate results are obtained on a submarine with the new apparatus, and there is a possibility that it can be used on an ordinary surface ship also. In about a month from now Dr. Meinesz will leave Holland on a submarine of the Dutch Navy, which will take the western route to Java, passing through the Panama Canal. He will use his new apparatus and expects to obtain a large number of gravity determinations in both the Atlantic and the Pacific Oceans during the six months required for the trip. The Coast and Geodetic Survey has loaned him one of its new radio recording sets which he will use in obtaining the rates of his gravity chronometers.

The results obtained on this trip will be of very great interest and value to geologists and geodecists. They will give the first accurate knowledge of variations of gravity over the two great bodies of water, the Atlantic and the Pacific, and will make possible a more complete test of the theory of isostasy than has ever been made. They will also furnish a very important test of the longitude term of the gravity formula derived by Helmert, Heiskanen, and others.

At the conclusion of this trip Dr. Meinesz will have circled the globe with his accurate gravity measures at sea. This is a pioneering accomplishment nearly as wonderful from a scientific standpoint as Magellan's was from a geographic.

U. S. Coast and Geodetic Survey,
Washington, D. C.

THE TREND OF GEODESY

WILLIAM BOWIE

For many years geodesy was considered to be a science devoted only to the determination of the shape and size of the earth. In general the operations necessary to make such determinations were base measurements, triangulation, and the determination of astronomic latitudes,

longitudes, and azimuths. The first geodetic work of any importance was the triangulation in Lapland and Peru to test Newton's view that the shape of the earth was that of an oblate spheroid. There was also an important piece of geodetic work involved in the extension of the French arc from which the shape and size of the earth were derived in order to establish the metric system.

Aside from the value of the triangulation and astronomic determinations of latitude, longitude and azimuth in the determination of the size and shape of the earth, the resulting data proved to be of the greatest value in correlating the surveys from which charts and maps of large areas were constructed.

The determination of the shape of the earth, but not its size, has frequently been made from value of gravity observed at widely separated points over the earth's surface, although this line of attack for the shape of the earth came much later than did the one which uses triangulation and astronomic data.

It was in trying to derive a figure of the earth from triangulation data that an important geophysical fact was discovered, that is, that mountain systems do not deflect the direction of gravity to the extent that the mass of the mountains would indicate. In the 1850's Airy and Pratt, working on geodetic data of India, arrived at the conclusion that under mountain systems there is a deficiency in density which supports or floats the portion of the crust involved in the mountain area. This deficiency, extending for an unknown depth below the earth's surface, has the effect of reducing the attraction of the mountain. It was from these studies of Pratt and Airy that the theory of isostasy was developed by Major C. E. Dutton of the U. S. Geological Survey in the 80's. His paper setting forth his theory was delivered at a meeting of the Philosophical Society of Washington on April 27, 1889, under the title "On some of the greater problems of physical geology." It was first published in the Bulletin of the Philosophical Society of Washington, vol. XI, 1892, pp. 51-64. As the edition was exhausted with the passage of years, the article, on account of its great importance, was reprinted in the Journal of the Washington Academy of Sciences, September 19, 1925, vol. 15, no. 15.

Dutton paved the way for geodesy to enter a much broader field than it had previously occupied. The whole question of earth physics is now more or less directly connected with geodetic observations and deductions. It may be said that the trend now of geodesy is along geophysical and geographic lines, in addition to purely dimensional ones which involve the shape and size of the earth.

About twenty-five years ago the Coast and Geodetic Survey entered on a vigorous campaign to test the theory of isostasy as outlined by Dutton. Some field work had been done during the 90's by that bureau, but the

results were inconclusive. The theory of isostasy was proved to be true and it may now be considered as a scientific principle or fact. Briefly stated, isostasy forces us to believe that the earth's crust is resting on what might be termed isostatic equilibrium on a subcrustal material that has little or no residual rigidity. A crust, on the other hand, has residual rigidity, as is proved by the fact that it can maintain a surface of unequal elevation. The theory of isostasy has been tested in widely separated areas with excellent results in every case. We seem to be justified in assuming that isostasy prevails throughout the earth's crust. With isostasy proved, the geodesist has been forced into a broader field covering geology, seismology, volcanology, and oceanography.

It may be said by some that, since the geodesist has proved the theory of isostasy to be a fact, anything else that is done towards applying isostasy to earth studies would be outside the realm of geodesy. But can this be true? I think that almost any study that is necessary in extending isostatic investigation beyond the mere proof of its existence may be legitimate geodetic work. We need to know to what extent isostasy applies to local topographic features. We need to know also how isostasy is maintained, what was the condition of the earth's crust at the beginning of the sedimentary age and what are the rates of vertical and horizontal movements of the past on the earth's surface. All of these, surely, are involved in the study of isostasy. Is not this another case of the boundaries between what we call separate and distinct sciences being removed? It is practically impossible today to draw separate lines between any of the sciences. Chemistry and physics are considered to be practically one and the same thing. The physicist is required to know much of chemistry and the chemist certainly must know much of physics.

For many years the variation of latitude has been considered a geodetic problem, although it is also an astronomical one. The geodesist, whose classical function is to determine the shape of the earth from triangulation and astronomic data, must know whether the axis of rotation of the earth and the axis of figure are the same or, if not, what their relationship is. Does it remain fixed, or is it variable? The International Geodetic Association, many years ago, attempted to solve these problems by the establishment of five variation of latitude stations, all placed along the 39th parallel of latitude in various parts of the world. Three of these stations, in Italy, Japan, and the United States, have been operated continuously for more than 25 years. One, also in the United States, was abandoned just before the war. The fifth, in Turkestan, was abandoned a few years ago.

From the variation of latitude data we are able to determine the elastic properties of the earth as a whole. Thus a phase of geodetic work becomes practically geophysics in the general sense of the latter term.

The geodetic work, in the form of triangulation and leveling, has been greatly extended in its use until today the engineer engaged on charting, surveying, and mapping and in many of the engineering problems of the country requires the accurate elevations and geographic positions furnished by geodesists.

We may summarize the situation by saying that geodetic work is taking its place with other earth sciences in solving the problem of why we have changes in elevations and geographic positions on the surface of the earth and that geodetic data are becoming of great value in industrial development. What was once a narrow field has become a very broad one.

U. S. Coast and Geodetic Survey,
Washington, D .C.

EXCESSIVE CASES OF LATERAL REFRACTION

J. L. RANNIE

Lateral, or horizontal, refraction is quite frequently encountered in the angular measurements of triangulation systems, but its occurrence is usually spasmodic and may usually be attributed to air currents or pockets on lines in proximity to buildings, mountain masses, etc. Two cases of consistent lateral refraction have occurred in Canada which permit the underlying causes in these cases to be investigated and, perhaps, explained.

An extended and persistent example of lateral refraction was met on the triangulation net of the St. Lawrence River and Gulf, the field work of which covered some 325 miles and extended over four seasons. In this net the lines along the river bank were so consistently "bent" *towards the river* that a practice had to be adopted of ending observations on these lines only when the results on at least two nights showed a satisfactory agreement. Lateral refraction affecting the observations by from 5 seconds to 15 seconds of arc was not at all uncommon, and it has been estimated that almost three times the amount of clear weather ordinarily necessary to secure the required program of observations was used to secure the required accuracy. Even with the precautions which were taken, the evidence shows a regular bending *towards the river* of the lines parallel to the river. This is evidenced by the error of closure of triangles, the sum of the three observed angles being less than the theoretical sum in the majority of cases.

From an illustration showing curved lines exaggerating the "bent" condition of the lines parallel to the river, it is obvious that the sums of the angles of all of the triangles of which the figures are composed would be less than they should be. The following table was compiled from the closure errors of the triangles used in the adjustment of this large net:

	Number	*Average error*
Triangles in which sum of angles was too small.....	42	—1."107
Triangles in which sum of angles was too large.....	12	+0."700

Had only accidental errors entered into the measurement of the angles of this net, approximately the same number of positive as negative closing errors would have been expected. The last column indicates that even where the sum of the angles was too large, the errors were probably reduced by the "bending" indicated above. This information may be stated in another way. In the adjustment of this net the large majority of the corrections to lines parallel to the river "unbent" these lines away from the river.

	Number	*Average correction*
Corrections which "unbent" lines away from river..	54	0."450
Corrections which produced opposite effect.....	12	0."257

This table indicates a great preponderance, both in number of bent lines and magnitude of the correction. In contrast to this tendency of the lines parallel to the river to bend towards the river, the adjustment gave to lines crossing the river 62 positive corrections averaging 0."343 and 61 negative corrections averaging 0."316. The errors on these lines are clearly of an accidental, rather than a constant, type.

A superficial explanation of the persistent occurrence of lateral refraction in this area is probably that the strata of air of different density frequently did not lie horizontal, as is generally assumed, but followed more or less closely the surface of the land. Lines along the hilly shore passed through strata which dipped towards the river, and the plane of the curved path of the ray of light, being perpendicular to the strata, was inclined towards the river. The light, hence, appeared above, and slightly to the river side of its true position instead of directly above, as would be the case were the strata of air horizontal. This theory accounts for the fact that on the lines across the river no evidence of horizontal refraction existed.

The season of 1925 provided further examples of the persistent occurrence of this phenomenon and permitted the underlying causes in certain cases to be still further investigated. During the hot weather, in the course of the measurement of a precise traverse on the railway tracks along the Skeena River in British Columbia, aggravated cases of lateral refraction occurred. In this case the lines were "bent" *away from the river* and towards the hills, just the opposite to the effect in the St. Lawrence River area noted above.

The railway runs in a general east-and-west direction along the north bank of the river at the base of cliffs many hundreds of feet high. The sun, therefore, shone on these cliffs during most of the day. Traverse courses were short, owing to the excessive curvature of the railway line, varying from 100 to 2,000 meters. An azimuth line connected stations about 5 miles apart, so that loops were formed which permitted the error of closure to be measured. Measurement of traverse angles made in strong sunlight consistently showed that the traverse lines were "bent" *towards the cliffs*, the angular error increasing with the length of the line. Re-observation of the angles at 65 traverse stations at night or on dull days disclosed errors of from three to five seconds on 100- to 200-meter lines and up to 20 seconds on lines near a mile in length. The sign of the error in all cases showed the lines to have been "bent" towards the cliffs.

The explanation advanced is that the air close to the cliffs became super-heated, much expanded and hence less dense than the air at equal elevations over the river. The layers of air of equal density or pressure therefore dipped as they approached the cliffs.

The refracted course of the rays of light passing through these layers of air of different density may have been tilted from a vertical even to a horizontal plane. Even in such a case the coefficient of refraction must have been from 0.2 to 0.5 to have produced the above effects, a very excessive figure.

The foregoing interpretation may be used to further explain the tilting of the air strata which was found in the St. Lawrence River area. The observations in this district were made on lights at night, when the land surface was cooling rapidly. This cooling would produce a contraction of the air with consequent greater density, and, as the land became cooler than the very large body of water, the strata of air of equal density would tilt upward towards the hills and produce the lateral bending so consistently noted.

Under this theory it might have been anticipated that the above "bending" of the lines towards the St. Lawrence River would not have occurred had the lines been observed in the daytime. Indeed the effect might have been the reverse on hot days.

Geodetic Survey of Canada,
Ottawa, Canada.

SECTION OF SEISMOLOGY

(Washington, D. C., April 30, 1926)

MINUTE COOLING EFFECTS REVEALED BY THE SEISMOGRAPH

E. A. Hodgson

The effects referred to were first observed at the Dominion Observatory, October 11, 1916. They consisted of rhythmic oscillations of a cement pier, following the disconnection, after a long period of equilibrium conditions, of a small electric heater, placed in the underground vault in which the pier in question supported a "Deformation Instrument" or tilt-measuring seismograph.

A series of experiments followed, which continued to December, 1920. A paper describing these was given, by title only, before the American Physical Society and Section B (Physics) of the American Association for the Advancement of Science, at the Chicago meeting, December 28-30, 1920. An abstract of this lecture was given in the Physical Review, vol. XVII, March, 1921, pp. 376-377. A complete account of the work was published as one of the series of Publications of the Dominion Observatory, Ottawa (vol. V, no. 2), with the title, The Effect of Cooling on a Cement Pier.

The publication, which is fully illustrated, describes the methods used to make certain that the oscillations of the light spot on the recording drum were caused by the movements of the pier and not through variations in the parts of the instrument. An attempt was also made to determine the nature of the movements of the pier and their magnitude.

By a specially arranged device, the sensitivity to tilt of the deformation instrument was shown to be such that, for the free pendulum period used (30 seconds), one millimeter displacement of the light spot on the record indicated a tilt of .0075 second of arc.

The experiments were not successful in determining the exact nature of the movements. It was not shown whether they were due to impulses, to tilts, or to torsional oscillations. If we assume that they were entirely due to tilt, the magnitude was of the order of a tenth of a second of arc for most of the sustained patterns on the record.

In February and March, 1922, an effort was made to find out how long the oscillations would continue. The heater was turned off and left off for five weeks. The cooling was slow and continuous for that period, as shown by a small Richard thermograph. The oscillations continued for the whole time. The "resonance pattern" (if one may so designate the regular sequence of excursions of the recording light spot) changed slowly from one form to another.

In the complete report the prediction is made that mountain peaks may be expected to oscillate when cooling after a hot afternoon sun has been warming up their western slopes.

The St. Lawrence earthquake of February 28, 1925, drew the attention of the Dominion Observatory to the need of a seismograph in that area. Accordingly a Milne-Shaw instrument was installed at Ste. Anna de la Pocatiere (on the south side of the St. Lawrence, about 90 miles below Quebec). Pending the drying out of the valley, a temporary station was obtained in the basement of the Agricultural School. This building rests on a flat shelf cut into the rock near the base of an outcrop of rock, approximately 150 feet high and of the proportions of a miniature mountain. The seismograph was mounted on the floor of the basement, which in turn was built directly on the rock.

April 10, 1925, was an unusually warm day, followed by a frosty night. The prediction was made that oscillations of the mountain would appear on the record. They did appear. The cooling caused a tilt which, strange to say, did not appear until nearly midnight. This was probably due to the location of the school, which was on the east side of the mountain and at its very foot. The oscillations began about 4 a. m. on April 11, and continued with approximate regularity for three hours. At that time their recording was interfered with by the boom fouling the bumper post.

These oscillations, if we interpret them as being due entirely to tilt, indicate a maximum flexure of .01 second of arc. The complete period of a cycle was about 80 seconds. The amplitude and period were both decreasing slightly when the movement was interfered with by the bumper stop.

Further experiments, both in the laboratory and in the field, are contemplated.

Dominion Observatory,
Ottawa, Canada.

NEW SEISMOLOGICAL TABLES

JAMES B. MACELWANE, S. J.

The title of the present paper on which the writer was asked to speak at this meeting of the American Geophysical Union has undoubtedly aroused in the minds of many the question of the necessity or advisability of new tables for earthquake waves. Why not standardize our results by adopting officially one of the sets of tables now in use instead of adding to the confusion by issuing new ones?

In 1903, John Milne[1] issued a set of tables in which he postulated

[1] B. A. Report, 1903, p. 84; also, Nature, vol. 67, April 9, 1903.

an outer mantle and an inner core, in both of which the velocity was assumed constant. In 1905 H. Benndorf[2] issued tables which were more nearly in accord with observation. He has the merit of being the first to call attention to evidence for a discontinuity at slight depth. His tables placed this break in the velocity of earthquake waves at a depth of five hundred kilometers. From there downward he postulated gradual increase of velocity. In 1906 R. D. Oldham[3] published tables which reverted to the hypothesis of a chordal path and constant velocity. But in the following year the well-known tables of Wiechert and Zoeppritz[4] were published. These mark a new era in seismometry. Another such epoch-making addition to our knowledge of travel times was the publication in 1909 and in 1914 of the researches of the two Mohorovičićs. In 1916 Otto Klotz combined these results in his Seismological Tables.[5] These tables are still in quite general use. Some combinations in them are unfortunate, particularly the travel times for PS, which are quite incorrect and make the transformed waves arrive before the direct transverse waves. This would seem to have come about by adding travel times for P and S for half the distance, thus neglecting Snell's Law for the angles of reflection. The transverse wave reflects at a lesser angle than the longitudinal, hence it goes deeper, and traverses a longer path than the longitudinal reflected wave. More recently, the Seismological Committee of the British Association[6] has issued tables for P,S, and S-P both in single degrees and to a great extent also in tenths of a degree up to 150° distance. But the curve for the travel times of P goes over into P′ and that of S into PS in the second quadrant. None of these tables can be expected to embody the recent observations on refracted and diffracted waves at great distances, and hence on the effect of proved discontinuities and of the core. The only tables which do take account of these factors are those of Gutenberg, 1914[7] and 1923,[8] those of A. and S. Mohorovičić, 1914,[9] 1921,[10] and 1925,[11] of Angenheister, 1921,[12] and with somewhat less precision, those of S. W. Visser,

[2] K. K. Akad. der Wiss. in Wien, Mitteilungen der Erdbebenkommission. Heft 29. 1905; Heft 31, 1906.

[3] Quart. Jour. Geol. Soc., vol. 62, p. 456.

[4] Nachr. der k. Ges. der Wiss. zu Göttingen, math.-phys. Kl., 1907.

[5] Publ. of the Dominion Observatory, vol. 3, no. 2, Ottawa, 1916.

[6] International Summary.

[7] Nachr. der Ges. der Wiss. math.-phys. Kl. 1914.

[8] Sieberg-Gutenberg. Erdbebenkunde, pp. 288-291.

[9] Bull. of the Acad. of Sci. and Arts of Jugoslavia, July, 1914, and manuscript.

[10] Acad. of Sci. and Arts of Jugoslavia, May 20, 1921, pp. 94-190.

[11] Publications du Bur. Centr. Seism. Intern., Ser. A, Travaux Scientifiques, fasc. 3.

[12] Nachr der K. Ges. der Wiss. zu Göttingen, math.-phys. Kl., 1921.

1921.[13] Recently an average table was published by G. Krumbach.[14] None of these are entirely complete or very closely interpolated.

Now there has been felt for many years the need of tables which would give at a glance the travel times of all the earthquake wave groups or phases which may be expected to arrive at a station situated a given distance from the epicenter of any earthquake. Such tables can be constructed by listing travel times for successive phases in parallel columns so that all those for any given distance appear on one horizontal line.

It was on that model and with this need in view, in 1911, that the Reverend Joseph S. Joliat, S. J., and the writer constructed and published in the Bulletin of Saint Louis University,[15] a table for the arrival times of phases up to an epicentral distance of 13,000 kilometers. That table was based on the most reliable data then available, particularly those of Wiechert and Zoeppritz, and gave distances in megameters, miles and degrees, but it was not interpolated more closely than to intervals of one hundred kilometers and is now, of course, obsolete.

In the summer of 1923 Dr. Perry Byerly and the writer, at the University of California, made up another set of tables which were distributed to a few friends for trial and were referred to by Dr. Byerly in the Bulletin of the Seismological Society of America.[16] These tables were far more elaborate than those of 1911 and form the model and groundwork of the new tables which have just been completed.

In the first place, in 1923, the question arose as to whether the tables should be built on kilometers, as most previous tables had been, or on degrees of arc as the British tables were. Dr. Byerly and the writer were doing so much work with a thirty-six inch globe at the time that we decided at once for one-tenth of a degree as our unit of distance. However, it is necessary very frequently to give the number of kilometers and in this country also of miles. Conversion from one to the other is always troublesome, and to avoid the necessity of it we decided to calculate and embody a conversion table in our set. This has been retained.

We decided to include travel times for the direct longitudinal and transverse waves and for three of their reflections, for both the surface groups of greatest prominence, the L or long, irregular waves at the beginning and the M or shorter, larger, more regular waves that follow, and finally for the returns of the surface waves, the W_2 group which

[13] Verhandelingen, No. 7, Kon. Magnet. en Meteor. Observatorium te Batavia, 1921.

[14] Zeitschr. für Geophysik, Bd. I, H, 8, Oct. 1925.

[15] Vol. 7, no. 5, pp. 23-25.

[16] Vol. 14, pp. 96-97.

travels by the longer arc and the W_2 group which arrives a second time after a complete circuit of the globe.

The travel time curves for the surface groups L and M were constructed by plotting for the former more than twelve hundred points and for the latter about eleven hundred points, representing observations of travel times as a function of distance and then drawing through the points thus plotted in each case an average curve. The velocity obtained for the L waves was 3.93 kilometers a second and for the M waves 3.42 kilometers a second. The latter figure is not far from the velocity, 3.46 kilometers a second, Cavasino [17] found for the return waves, and it happens to be exactly that found by Angenheister [18] in 1906. The 1200 and 1100 observations used by us were carefully selected for their reliability from the lists in the British Association Summary.

However, the great mass of excellent observations which have become available since the summer of 1923 has made it advisable to reconstruct the parts of the table which refer to the preliminary phases. This was done at St. Louis University during the past months. The travel times for the normal longitudinal and transverse waves published by the Mohorovičićs in 1921 have proved so near an approximation to reality under trying tests that they have been included bodily and all time differences have been referred to them. The travel times for some of the reflections and for all of the core waves have been taken from Gutenberg's 1923 tables. There is nothing at present more reliable.

The tables are divided into four parts. The first part includes the travel times and differences for thirteen phases direct and reflected, for epicentral distances between ten and one hundred and three degrees. The tables begin with a distance of ten degrees from the epicenter, because at distances shorter than this the excellent Mohorovičić-Rothé multiple tables are available for different depths of focus. This varying depth, together with the subcrustal discontinuity, makes the use of a single set of tables for near earthquakes quite impossible.

The second part is composed of travel times, referred to the time at the origin, of sixteen phases between ninety and one hundred and eighty degrees of distance from the epicenter. They are mostly the direct and reflected groups, but include P between one hundred and three and one hundred and forty-seven degrees distance, which is a diffraction phenomenon. They also include P′ between one hundred degrees and one hundred and forty-two degrees where it seems to be a diffraction phenomenon and between one hundred and forty-three and one hundred and eighty where it is a refracted wave coming through the core of the earth.

[17] Boll. della Soc. Sism. Italiana, vol. 23, 1920-21.
[18] Nachr. der Ges. der Wiss. zu Göttingen, math.-phys. Kl., 1906.

The third part will contain those further waves that have been affected by the core of the earth as far as data are available for them in Gutenberg's 1914 and 1923 tables.

The fourth part is devoted to waves reflected on the further side of the earth.

The tables are being issued in this preliminary form in order that they may be tested, criticized and improved in every way possible before they are finally printed for general distribution.

It is hoped that these tables will stimulate the study of the seismograms of earthquakes at greater distances. Hitherto, they seem to have frightened by their complexity all observers who were not specialists in the science. In fact, until quite recently, the first reports on very distant earthquakes which were issued by many stations were erroneous and misleading, because the observers were looking in the records of remote earthquakes for the phases characteristic of shorter distances and overlooking the obvious earmarks of a very distant shock.

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SEISMOLOGICAL INVESTIGATIONS AND OCEANOGRAPHY

T. WAYLAND VAUGHAN

The results of seismological researches are of significance to the student of oceanography in the same way that they are to any other student of general geophysics. Most of the hydrosphere, one of the shells of material which compose the earth, is contained in the ocean basins, which are bounded above by the atmosphere and below by the lithosphere, two other shells of earth substance. If the student of the ocean wishes to understand the relations of the hydrosphere to the other components of the earth he must pay attention to seismology and studies of earth tides, for those are important sources of information on the internal constitution of the earth.

The ocean covers about 71 per cent of the surface of the solid. On an areal basis, therefore, 71 per cent of the earthquakes would be expected to originate below sea level. It is now known that earthquakes are due to deformation in the lithosphere. Although this deformation may result from several kinds of causes, the most important kind expresses itself in faulting, which usually, but not invariably, produces change in level on the two sides of a fault line. Seismological research, therefore, offers assistance in explaining important features in the relief of the sea bottom and certain features of the ocean margins.

It is now generally admitted that the continents stand high because they are composed of lighter, and the ocean basins lie low because they

are underlain by denser, material. The contact zones between the lighter continental and denser suboceanic masses are sites of earth strains, the marginal continental rocks tending toward upfolding and the suboceanic rocks toward downfolding. We perhaps need not consider the relative merits of whether the continents are overfolded and overthrust on the suboceanic masses or whether the suboceanic rocks are underthrust with reference to the continental margins. These marginal zones are the sites of important earth movements, in them lie the greatest seismic zones of the earth, and they are of critical importance to the oceanographer.

Certain facts illustrating the relations indicated are too well known to require more than briefest mention. The Pacific Ocean is margined by mountains from southern Chile northward to Alaska, thence by way of the Aleutian Arc to northeastern Asia, and thence southward to the East Indies and on to New Zealand. On the seaward side of the mountains is the ring of Pacific deeps. The zone between mountains and deeps, and probably involving both, is the circum-Pacific earthquake zone. The zone passes westward by way of the Himalayas to the Mediterranean region of Europe and Africa, and eastward it crosses southern Mexico and follows around the Antillean arcs. Throughout most of the vast region sketched in outline, seismology is an essential part of oceanography.

In order to be more specific regarding the close connection between seismology and oceanography, the ocean deeps of the Caribbean region will be cited as instances. Rev. J. Scherer, director of the Meteorologic Observatory of the Seminary-College St. Martial, Port-au-Prince, Haiti, appears to have been the first definitely to have correlated earthquakes with the formation of the Caribbean deeps.[1] The subject has also been discussed by Vaughan, Taber, and Woodring.[2] Woodring interprets the Bartlett Deep as a synclinal trough bounded on the sides by high angle thrust faults, basing his interpretation on analogy with the observable structure of the margins of the Cul-de-Sac Plain of Haiti. All of the interpretations agree in that to faulting is attributed an important rôle in the formation of the trough. Those who may wish to follow the subject in detail may consult the papers listed by Woodring in the volume cited above. Taber is of the opinion that many of the West Indian earthquakes are of submarine origin.

Two instances of the convincing establishment of a submarine site for the origin of West Indian earthquakes will be given. The first is that

[1] Scherer, J., Les tremblements de terre de l'île d'Haiti dans leur rapports avec le relief du sol et les fosses maritimes qui l'entourent: Observ. Météorol. Sém-Coll. St. Martial. Bull. semest., July-Dec., 1912, pp. 132-139, 1913.

[2] Woodring, W. P., Geology of the Republic of Haiti, pp. 331-353, 1924, gives references to literature as well as the results of his own studies.

of the Virgin Islands earthquakes of 1867-1868,[3] concerning which Reid and Taber say:

"The earthquake and sea waves seem to have been propagated from an origin on the north side of the Anegada channel not far from latitude 18° 10′ north and longitude 65° west, or about fifteen or twenty kilometers south of St. Thomas."

A statement of the evidence on which this conclusion is based is then given in the article from which the quotation above is taken.

The second instance is that of the Porto Rico earthquakes of October-November, 1918.[4] Regarding the site of the origin of these earth vibrations, Reid and Taber say:

"All of the evidence collected is in accord with the conclusion that the earth vibrations and sea wave were propagated from an origin in the northeastern part of Mona Passage. As the seat of the disturbance was under the ocean, at a depth of possibly 1,000 fathoms, it is impossible to determine its exact location; but it could not have been far from latitude 18° 30′ north and longitude 67° 20′ west, or, roughly, fifteen kilometers west of Point Borinquen lighthouse."

The passage quoted above is followed in the original article by a résumé of the facts on which the opinion is based.

I have spent a great deal of time either drawing profiles of the sea bottom in the Antilles or measuring the slopes according to the hydrographic charts. Submarine faulting has been one of the most important factors in determining the character of the sea bottom in the Antillean region.

A large number of instances of the submarine origin of earthquakes in the Pacific could be quickly compiled—they are circum-Pacific—but to do so seems unnecessary for this brief statement.

Faulting in some regions determines the character of the shoreline. An excellent illustration of such an influence is furnished by New Zealand, whose shore features have been admirably studied by C. A. Cotton.[5]

It is hoped that the foregoing summary statement has made clear that seismology can be regarded almost as a branch of oceanography, because seismology is one of the most important sources of information on the constitution of the interior of the earth, and it is necessary for understanding important features of the relief of the sea bottom and for interpreting the origin of certain types of shoreline topography. Every oceanographic institution should have as a part of its equipment properly in-

[3] Reid, H. F., and Taber, Stephen. The Virgin Island earthquakes of 1867-1868: Seismol. Soc. Amer. Bull., vol. 10, pp. 9-30, 1920.

[4] Reid, H. F., and Taber, Stephen, The Porto Rico earthquakes of October-November, 1918: Seismol. Soc. Amer. Bull., vol. 9, pp. 95-127, 1919.

[5] Cotton, C. A., Geomorphology of New Zealand, pp. 430-435, 1922. For additional references see bibliography on p. 452.

stalled and operated seismographs, and these and an automatically recording tide gauge should be tied into the same system for recording time, for seismographs and tide gauges are mutually complementary instruments.

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RELATION OF EARTHQUAKES TO ISOSTASY

WILLIAM BOWIE

While the isostasist can assist the seismologist in the study of earthquakes, their cause and effect, at the same time the seismologist can be of great assistance to the isostasist.

With the proof of isostasy, we are led to believe that the earth's crust must be quite weak in order that the adjustment may be so nearly perfect as has been found.

The earth's crust has been found to be of the order of magnitude of sixty miles in thickness. This depth was determined mathematically from the consideration of the differences between the theoretical and the observed values of gravity and the theoretical and observed deflections of the vertical. Such a depth as has been found is an average and it is reasonably certain that the compensation extends in places below sixty miles.

The seismologist has shown us that thousands of earthquakes occur yearly and this indicates a very weak crust; he has also shown by an analysis of the rates and directions of propagations of the seismic wave that the earth is solid throughout.

Isostasy is a static condition of the earth's material, merely a condition of rest which is, of course, disturbed by the shifting of materials horizontally at the surface of the earth or below the crust. The earthquake phenomenon, on the other hand, is a dynamic phenomenon involving the expenditure of energy due to stresses set up by changes in volume or shifting of matter. From the earthquake may be discovered the rate at which changes are taking place in the earth and on the surface, and the magnitude of the forces which are acting.

The seismologist may be able to tell the isostasist the limiting depth to which earthquakes extend. According to the isostatic principle which requires a crust with residual rigidity and a subcrustal material which is plastic to long-continued stresses, no earthquake should occur below the crust. If the seismologist can give accurate data as to the limiting depth of the earthquake epicenter, there will be another line of attack as to the thickness of the outer layer of the earth within which heterogeneous densities may be maintained.

A consideration of the mechanics or physics of the earth's crust based on the proof of isostasy would lead us to believe that there can be no horizontal movement of crustal material from a low area towards a high one. With the earth's crust in equilibrium, the stress difference would be from the high area toward the low one all the way from the surface down to the lower limit of the crust. At the latter place the stress differences would be zero. If two contiguous portions of the crust in equilibrium were to have a transfer of load at the surface from the high to the low one, and if no movement downward or upward should take place to restore the isostatic equilibrium, then the stress difference between the two blocks would be zero at a depth somewhat above the lower limit of the crust. The perfection of isostatic equilibrium, however, would lead us to believe that the zero stress difference would not be raised very far.

The seismologist can tell us whether at faults the predominant movement is horizontal or vertical at the time of an earthquake. If it is horizontal and of wide extent, then it is possible the conclusion of the isostasist, that there is no great horizontal movement within the crustal material from a low area to a high one, might be found to be erroneous.

It has been found that the topographic feature, which is about thirty miles in diameter and three thousand feet thick, is at least largely compensated. This gives an idea as to the degree to which isostasy obtains.

The isostasist confines himself to analyses of geodetic data and to tests involving the distribution of densities. From this he learns whether the earth has a crust and, if so, whether large portions of it can be maintained in a non-isostatic condition. When he goes beyond this rather narrow field, he is working in the realm of geophysics and geology. It is in these two latter branches of earth sciences that the seismologist has the opportunity to be of great assistance to the isostasist.

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NOTE ON THE INFLUENCE OF THE MOON ON EARTHQUAKES

H. F. Reid

Since the time of Perrey much statistical study has been devoted to seeking a relation between the frequency of earthquakes and the position of the moon. Different investigators have arrived at contradictory conclusions; so that the results of all this work have been disappointing. I think we shall see the reason for this if we look at the problem from a dynamical standpoint. The earth is tidally distorted by the moon and stresses must be set up which will add to those growing independently in the earth and influence the time of occurrence of a particular earth-

quake, and a preliminary estimate indicates that this influence may be important. Yet the influence depends not only upon the position of the moon, but also upon the direction of the strike of the fault where the fracture is about to take place with respect to the azimuth of the moon and on the dip of the fault. Of two faults similarly situated with respect to the moon, but with the downthrow on opposite sides of the fault, one will be advanced and the other retarded. In any large catalogue of earthquakes, faults will be involved striking in various directions, with different dips and with downthrown sides both towards and away from the moon. We conclude, therefore, that although the moon may have a definite effect on any particular fault, the hour-angle for its greatest effect will differ much for different faults, and no hour-angle will be especially predominant when a long list of earthquakes are studied statistically. This is only a preliminary note on a subject still under investigation.

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SECTION OF METEOROLOGY

(Washington, D. C., April 30, 1926)

In the absence from the city of Professor C. F. Marvin, who was scheduled to open the program, the Chairman, C. G. Abbot, by request, presented a report on incidents connected with his recent journeys in Europe, Asia, and Africa having for their purpose the establishment of a station for determining daily values of the solar constant of radiation. Funds for the support of this station have been provided by the National Geographic Society. He announced the selection of a site in Southwest Africa where the meteorological conditions promised to be even more favorable than in Chile.

DISCUSSION OF QUESTIONS INVOLVING INTERNATIONAL COOPERATION

1. "Proposition for greater uniformity in pyrheliometric observations" (H. H. Kimball, U. S. Weather Bureau). An examination of pyrheliometric readings made at nearly one hundred points of observation during the last forty years indicates that greater uniformity of method and careful intercomparison of pyrheliometers is desirable. In a majority of cases the altitude of the Sun at the time of observation is given. Such observations can be summarized in such a way as to be directly comparable, provided the constants of the pyrheliometers permit of reducing all the readings to the same pyrheliometric scale. Intercomparison of the Smithsonian silver disk pyrheliometer, the Marvin silver disk pyrheliometer, and the Angström electrical compensation pyrheliometer make it possible to reduce the readings of these instruments to a common scale, provided, of course, the instruments are all in good condition. In the case of observations taken near noon only, as is the case at some stations, it is not so easy to summarize them in such a way that they are comparable with readings made at other stations; although valuable, they require a great deal of labor to adapt them to many meteorological problems.

2. "Measurements of the ultra-violet of solar radiation" (W. J. Humphreys, U. S. Weather Bureau). Since surprisingly and, as yet unaccounted for, great variations in the ratios of the ultra-violet to the green portions of the solar radiation have been reported, and since the shorter wave-length part of insolation is of great physiological importance to both animals and vegetables, it seems desirable that careful measurements of the ultra-violet be made at all the principal pyrheliometric stations.

3. "Shall the intensity of solar radiation be expressed in units of heat or power?" (H. H. Kimball, U. S. Weather Bureau). It is now almost the universal practice to record solar-radiation intensities in units of heat, namely, gram-calories per minute per square centimeter. More and more, however, we are coming to think of solar thermal energy. Therefore, the question arises why the intensity should not be expressed in units of energy with which we are familiar.

4. "The correlation of solar-radiation data with terrestrial weather" (A. J. Henry, U. S. Weather Bureau). In view of the probable early completion of arrangements for measures of the constant of solar radiation at one additional station in Africa, it is advisable that organized meterological services throughout the world undertake the correlation of all available measures of solar radiation with terrestrial weather, having due regard for the claims of provisional value that have been advanced with respect to them. While individual research on the problem is not discouraged, it is believed that tests by organized services that are charged with the duty of forecasting the weather hold out greater promise of finality than do those made by individuals.

SECTION OF TERRESTRIAL MAGNETISM AND ELECTRICITY

(Washington, D. C., April 29, 1926)

RESULTS OF RECENT EXPERIMENTS ON COSMIC RAYS

R. A. MILLIKAN

Abstract.—The paper presented a synopsis of the methods used and results obtained by the author and his associates, I. S. Bowen, R. M. Otis, and G. H. Cameron, in the investigations on high-frequency rays of cosmic origin (1) in sounding balloon observations at extreme altitudes, (2) by mountain-peak and airplane observations, and (3) by measurements in snow-fed lakes at high altitudes.[1]

Discharge rate of an electroscope at altitudes from 5 to 15.5 km.—Four specially designed instruments, each comprising a recording electroscope, thermometer, and barometer and each weighing but 190 gr., were sent up with sounding balloons from Kelly Field, Texas. Three were recovered, and of these two had satisfactory records of their flight, during which they reached altitudes of 11.2 and 15.5 km., respectively. A comparison of the recorded electroscope reading at the 5-km. level during ascent, with the reading at the same level, during descent, shows that the average discharge rate of the electroscope while between the 5-km. level and the 15.5-km. level was about three times its discharge rate at the surface of the earth, and corresponded in this particular instrument to an average rate of production of ions of 46.2 ions per cc. per sec. This is only 25 per cent of the value to be expected from the observations of Hess and of Kolhörster, and constitutes definite proof that there exists no penetrating radiation of cosmic origin having an absorption coefficient as large as 0.57 per meter of water.

Mountain-peak and airplane observations.—The elimination in penetrating ray experiments of temperature and pressure effects is accomplished through new features in the design of Wulf electroscopes, but especially through immediate reduction *in situ* of all deflections to volts. When suitable precautions are taken for eliminating the activity of adjacent rocks, both airplane and mountain-peak observations agree in showing a definite variation of the penetrating radiation with altitude alone. Within the limits of experimental error, all observations are consistent in showing no dependence of the penetrating radiation upon the time of day or upon the position of heavenly bodies. Absorption experiments made on Pikes Peak with lead sheets 4.8 cm. thick furnish evidence for the existence on mountain peaks of copious rays of local origin

[1] *Cf.* R. A. Millikan, Proc. Nat. Acad. Sci., vol. 12, pp. 48-55, January 1926; R. A. Millikan and I. S. Bowen, Phys. Rev., vol. 27, pp. 353-361, April 1926; R. A. Millikan and R. M. Otis, Phys. Rev., vol. 27, pp. 645-658, June 1926; and R. A. Millikan and G. H. Cameron, Phys. Rev., vol. 28, pp. 851-868, November 1926.

of no greater hardness than that of gamma-rays. If all the rays found on the peak are assumed to be homogeneous, their absorption coefficient is about 3.1 per meter of water, or near that of ordinary gamma-rays. These experiments, however, furnish no definite evidence for the existence of very penetrating rays of cosmic origin. Such rays, if they exist, cannot produce as much as 2 ions per cc. per sec. at sea-level if they have an absorption coefficient not less than 0.25 per meter of water. If cosmic rays exist at all, they must be less intense than this, or else they must be more penetrating than anyone has as yet suggested.

Measurements in snow-fed lakes at high altitudes.—The following synopsis gives the results of observations made in snow-fed lakes at high altitudes: (1) Absorption experiments in Muir Lake (alt. 11,800 feet). The sinking of sealed electroscope No. 3 in Muir Lake showed an ionization decreasing steadily with depth, from 13.3 ions per cc. per sec. at the surface to 3.6 ions at 50 feet below the surface, below which there was no further decrease. The absorption curve of electroscope No. 3 was in excellent agreement with that of No. 1. (2) Absorption experiments in Arrowhead Lake (alt. 5,100 feet). The electroscope readings in Arrowhead Lake correspond uniformly to readings six feet deeper in Muir Lake. This difference is the exact water equivalent of the absorption of the atmosphere between the two elevations. All readings of both electroscopes fit satisfactorily upon a single curve relating ionization to depth beneath the surface of the atmosphere in equivalent meters of water. (3) Rays of cosmic origin. (1) and (2) combined with the failure to detect any systematic diurnal variation in tests of a number of days' duration at high altitudes, constitute new and quite unambiguous evidence for the existence of very hard etherial rays of cosmic origin entering the earth uniformly from all directions. (4) Spectral distribution of cosmic rays. No single absorption coefficient is found to fit the absorption curve, the lower end of which requires a coefficient of 0.18 per meter of water; the upper end a coefficient of 0.30 per meter of water. These coefficients correspond, by Compton's equations, to wave-lengths $\lambda = 0.00038$ A. and $\lambda = 0.00063$ A. These are fifty times the frequencies of ordinary gamma-rays, $\lambda = 0.025$ A., and the former corresponds to an energy of 32,000,000 volts. (5) Number of pairs of ions due to cosmic rays. The observed number of pairs of ions in electroscope No. 1 due to cosmic rays is about 1.3 at sea-level, 2.6 at 1,600 meters, 4.8 at 3,600 meters, 5.9 at 4,300 meters. (6) Stimulated secondary rays. Theoretically, cosmic rays of the foregoing energy should not stimulate ether waves of gamma-ray hardness, but should produce beta-rays capable of penetrating brass walls 5 mm. thick. The observations present evidence of rays of about this hardness, increasing systematically with altitude in rough proportionality to the intensity of the cosmic rays.

This evidence is not completely convincing because of inability thus far to eliminate the effects of the gamma-rays from the underlying rocks. (7) Origin of cosmic rays. Evidence is presented that these rays do not result from the union of protons with negative electrons, but that they are rather due to nuclear changes of about one-thirtieth the energy corresponding to such union, taking place throughout the depths of the universe.

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IMPROVEMENTS IN MAGNETIC RECORDING INSTRUMENTS TO FIT THEM FOR SPECIAL INVESTIGATIONS

N. H. Heck

The Coast and Geodetic Survey has for a number of years been laboring with the problem of doing the necessary work on its routine publications of observatory results in Terrestrial Magnetism, a problem which has been made more difficult by the assignment of work in seismology to the same Division. It has not, however, overlooked the fact that in order to accomplish this successfully it is necessary to study and improve the instruments. The subject of this symposium is the development of special instruments, and I will not be able to contribute greatly to this part of the subject. However, there have been some fundamental needs which must be met before our standard instruments develop their full capabilities. It is obvious that if a problem can be solved by a slight adaptation of present instruments and methods, the chances of its solution being undertaken are greatly increased. In this respect there have been, I think, a number of substantial contributions.

In 1924 George Hartnell, observer-in-charge of the Cheltenham Magnetic Observatory, Cheltenham, Maryland, prepared a study of the horizontal intensity variometer, which is published as Special Publication No. 89 of the Coast and Geodetic Survey. In this publication he treated the subject in an exhaustive manner. A number of suggestions as to the improvement of instruments were made, and in order to carry these out a small experimental building was erected. This building has proved of the greatest value ever since, and a number of important problems have been worked out there. So far as the Coast and Geodetic Survey is concerned, the study of temperature compensation of the H variometer has been the most important. The method and some of the results are given in the Journal of Terrestrial Magnetism for September, 1925. The method has so much promise that a compensated variometer is now in use in Porto Rico and one is being prepared for use at Cheltenham. The adaptation is simple. A suitable magnet is placed at such a distance that the field at the suspended magnet is one-half that of the earth's field.

It can be shown theoretically and proved by experiment that in this case there is accurate compensation. There seems to be no good reason why this plan should not be universally adopted. Even if the compensation is not quite perfect, there is a great advantage in having a small temperature coefficient. With temperature compensation, the H curve can be interpreted in absolute values simply by applying the scale value and the base line. This in turn makes possible a method of direct scaling of the magnetograms. This is now being done at Cheltenham, and it is hoped that eventually a single scaling at the observatories will suffice, except for a slight final revision. The only objection to this plan is that the scaling must be delayed several months in order that the scale value and base lines may be worked out.

The next important line of attack, which has a bearing both on routine and in investigations, is the improvement of instruments to obtain scale values and base lines which will not be subject to sudden changes for instrumental reasons. In view of the accuracy of the measurements this may not be entirely obtainable; but all those who are directing magnetic observatories know that there is a great need for a vertical intensity variometer which will give a better performance in these respects. The Coast and Geodetic Survey and the Carnegie Institution of Washington are both deeply concerned with this problem and are bending their efforts to a solution. It is hoped that in a year from now a more satisfactory instrument will be either in use or in the process of development.

Another important point is the recording apparatus. It is well known that difficulties are involved in securing uniform rotation of a recording drum and most of the early attempts have been in fact very crude as compared with present standards. It is now possible to secure accuracy according to the needs even to one ten-thousandth of a second in time. The difficulties naturally increase with the requirements of accuracy. In recording the magnetic records there are special difficulties, due to the fact that the recording apparatus must be practically non-magnetic. It seems, however, that the requirement that it be possible to scale times from the records which are correct within a few seconds is not unattainable. Such accuracy is called for in such investigations as that of the propagation of magnetic storms. Ordinarily such accuracy is not required. In this connection I may state that electrical methods may be used in a magnetic observatory if special precautions are taken. This will probably be brought out more clearly by Mr. Fleming.

The fact that the Coast and Geodetic Survey is carrying on at the same time investigations of magnetic and of seismological problems, and of acoustic problems as well, is promising of results, because all of these problems have a great deal in common. The solution of a problem in any one of these subjects may have a direct bearing on a solution in another.

Another very promising feature in the present situation is that the

Coast and Geodetic Survey and the Department of Terrestrial Magnetism are working together in solving such problems. Each is making an important contribution without overlapping the activity of the other. Such a spirit is more promising for the future than the actual state of progress at the present time.

In the improvement of optical systems of our magnetic instruments the Navy Department has been of great assistance.

In conclusion I wish to express my opinion that instruments for special investigation should hereafter have the qualities of compensation for temperature, reasonable constancy of base lines and scale values, uniform rotation of recording drums, and good optical systems. The question of whether special apparatus should be developed, or whether we should adapt the present instruments modified as indicated, is then one which should be decided in accordance with the demands of the special problem.

U. S. Coast and Geodetic Survey,
Washington, D. C.

IMPROVEMENTS IN MAGNETOGRAPHS AND VARIOMETERS FOR OBSERVATORY AND FIELD USE

J. A. Fleming

An outstanding need in recording devices for continuous registration of the magnetic elements is better time control. At present the Eschenhagen magnetograph is the one most generally used at observatories. It depends for time control upon short breaks each hour in the base-line produced by a cam and lever actuating a shutter to cut off, for from one to two minutes, the beam of light making the base-line. With such a device, usually operated by the same clock as that driving the rotating drum on which the photographic sheet is placed, parallax of the moving-mirror reflected beam as referred to the fixed-mirror reflected beam may be a serious matter calling for correction; this may arise from lack of parallelism of the horizontal axis of the condensing cylindrical lens in the recorder and of the axis of rotation of the recording cylinder, lack of appropriate adjustment of the mirror systems particularly as regards verticality when swinging freely, etc. The adjustment, so far as the first is concerned, is comparatively easy, but not so as regards the second. Since the time-scale usually employed is 20 millimeters to the hour or one-third millimeter to one minute of time, the error of parallax may become an important consideration, the more so as it may not be constant with varying ordinate. A longer time-scale might help, but economically this is not feasible in view of the greater expense necessitated for paper, for attendance, and for reduction.

Of late, a great deal of attention is being given the study of times of beginning of magnetic storms of various types, chief among these being

those usually designated "sudden commencements." Examination of records of such storms, for example, that of November 1, 1924, indicates characteristic features common to all of the observatories, but some of the details such as impulse at the beginning and character of first maximum disturbance following the sudden commencement show wide variation. Any question as to compilation of times of beginning is thus subject to two uncertainties, (*a*) as to the definite marking of the particular impulse starting the sudden commencement and (*b*) as to the exact time of this beginning, once careful study has indicated the same point of storm reference. We may hope to eliminate the first by a careful study of the original records, or, preferably, enlargements of them; but time control must be improved and methods developed making possible a precision of scaling for time comparable with any uncertainty concerned in the period or inertia of the moving system. Thus for such records an accuracy of one-fourth minute of time may be considered as a reasonable requirement; that is, the determination of a point on the time-scale to about 0.1 millimeter.

Irregularities of clock performance or non-uniform shrinkage in the photographic paper upon development, therefore, must be controlled as well as the adjustments referred to above. Obviously time-lines of satisfactory intensity once each hour, extending across the width of the record and made entirely independently of the driving clock, for example, by an electric time-device, offer a solution, provided the relation with the time-element of the recorded curve to these time-lines may be fixed. To do this, calls for some device by which exact times may be recorded at intervals by means of the moving mirror of the variometer. This may be accomplished by using a second slit at the source of illumination which may be automatically opened at fixed times and thus record for a brief exposure spots to one side of the recorded curve and of the recorded base-line. A second method, and one which has the advantage of giving at the same time data for scale-value determinations, may be effected by centering Helmholtz-Gaugain coils of suitable dimensions and orientations about each variometer and then passing, for short intervals at fixed times, first a small positive and then a like negative current through the coils, thus producing deflections on either side of the recorded curve. Exact measures of the photographic record then provide quite sufficient control on the relation of the time-lines to the time-scale of the curve. Messrs. Parkinson, Huff, and Goldsmith, of the Department of Terrestrial Magnetism, have been carrying on this development work in the experimental building at the Cheltenham Magnetic Observatory of the United States Coast and Geodetic Survey, where they have the hearty cooperation of Mr. G. Hartnell, Observer-in-Charge.

The results of earlier and recent investigations of possible correlations between the magnetic and electric activities of the Earth and solar ac-

tivity, particularly those of Bauer, Peters, Chree, Rodés, and others, emphasize the desirability of having at solar observatories some simple recording device for one or more of the magnetic elements, so arranged that the magnetic state of the Earth may be noted visually at any time and from time to time it may be determined whether any natural magnetic disturbance exists, thus permitting an intensive program of solar observations during such times. The importance of this subject has been emphasized by a resolution of the committee appointed by the International Research Council for the study of solar and terrestrial relationships (Dr. S. Chapman, Chairman). This resolution, favorably acted upon at the Brussels meeting, last July, reads as follows:

"The Committee recommends that solar observatories should make additional observations on the sun, as nearly continuous as possible, at or about the times when magnetic storms are in progress, or when they may be expected in accordance with the 27-day recurrence-tendency. This would necessitate the organization of a service for the supply of information to solar observatories as to magnetic storms, prospective or in progress. The Committee recommends that Dr. L. A. Bauer, the Secretary of the Section of Terrestrial Magnetism and Electricity of the International Union for Geodesy and Geophysics, be asked to formulate a scheme for this service."

Acting on this suggestion, the Mount Wilson Observatory and the Department of Terrestrial Magnetism hope to cooperate in carrying out such suggestions and plans as may be developed. Meanwhile, consideration is being given the application of the Eschenhagen type of variometer by so mounting it that, while recording photographically, the introduction of a prism or mirror in the course of the recording light-beam may give a visual projection on a ground-glass screen. To determine whether magnetic conditions are normal or disturbed, use can be made of the previous month's mean curve for normal days as recorded by the instrument; a simple clock-operated device can be made to show on the ground-glass screen the portion of the curve corresponding to any time of day, thus always affording visual means of estimating the general character of the Earth's magnetic activity. The first experimental work might be confined to the horizontal-intensity variometer, suitable control magnets being mounted for temperature compensation following the method originally developed at Potsdam and more recently applied by Mr. Hartnell.

It has been suggested that the declination variometer might be as well suited as the horizontal-intensity variometer, if suitable control magnets were mounted to greatly increase the sensitivity. In general, however, it appears that the horizontal intensity may be a better gauge of magnetic activity. The investigations by Bauer and Peters indicate that perhaps in such work the vertical intensity may be more suited for the study of possible correlations. The present type of vertical-intensity variometer

has certain mechanical defects inherent to pivot suspensions which must be eliminated to obtain greater constancy of performance. As Commander Heck has stated, the Coast and Geodetic Survey and the Department of Terrestrial Magnetism are cooperating in improving the design of the vertical-intensity instrument, the Department approaching the problem through electrical methods.

Recently, increasing emphasis has been centered on the study of the change with geographic position of the diurnal variations of the magnetic elements, and the observers of the Department of Terrestrial Magnetism have been obtaining continuous observations during the daylight hours at stations in all parts of the world, using the magnetometer attachment on one day to obtain such variations in declination and horizontal intensity simultaneously, and the inductor attachment on a second day to obtain such variations in inclination. This application of the inductor in field observation of variations gives quite satisfactory results directly, without the necessity of corrections on account of temperature changes when using intensity variometers.

That diurnal and secular variations may have relationships depending upon locally disturbed conditions, has indicated the need of instruments that may be used for rapid surveys of locally disturbed areas. Such instruments have application not only in obtaining data of this kind but also in economic geology. Thus, in the case of certain conditions of magnetic anomaly or in the event of the intrusion of nonmagnetic material, for example, a salt dome, in a formation of otherwise uniform magnetic character, such instruments afford a possible means of determining geological conditions and of making mineral surveys. Instruments used in such work include the universal magnetic variometer and magnetic field-balance of Schmidt's design, the Rühstrat horizontal-intensity variometer, and the earth inductor and compass-variometer of the Carnegie Institution of Washington.

The universal magnetic variometer as designed by Schmidt is used mainly for the determination of the variations of declination and horizontal intensity; the compass needle is suspended on a thin wire and the readings are effected with a telescope, mirror, and scale, the sighting being done with a telescope. The deflecting magnets are used to compensate the horizontal component of the Earth's field by moving them around and along the vertical axis of the instrument. A type of this variometer is also constructed for vertical intensity, this field-balance consisting primarily of a light magnetic needle swinging in a vertical plane attached to a thread kept horizontal by tension, readings being made by telescope, mirror, and scale.

The Rühstrat horizontal variometer utilizes needles with double-pivoted suspensions. Its sensitivity is altered by the slow-motion adjustment of an auxiliary bar-magnet.

For regions where the inclination is 70° or less, the C. I. W. earth inductor in connection with its field galvanometer is well adapted in the rapid surveys of regions of magnetic anomaly or of suspected mineral deposits. It is possible to determine in a few minutes of time at any station the value of magnetic inclination with an accuracy of one-quarter minute. In one such survey, where the value of the declination was about 61° and extreme ranges in vertical intensity and horizontal-intensity values were 400 and 280 gammas (one gamma = 0.00001 C. G. S. unit), the corresponding difference in inclination deduced for the two points of maximum and minimum values is 35 minutes of arc. Thus the earth inductor would have served excellently for the rapid delineation of the magnetic disturbances over this area, particularly in conjunction with an instrument capable of like rapid and accurate observation in horizontal intensity.

Compass-variometers designed by the Department of Terrestrial Magnetism suitable for the investigation of local magnetic disturbances, the detection of effects caused by hidden magnetic materials, and for register ing intensity variations with high precision, involve the following principal. Two magnets of equal magnetic intensity are suspended independently one above the other and so mounted that the distance between them may be varied to obtain a fixed horizontal deflection-angle for a particular, but not necessarily known, intensity of field. The sensitivity of such an instrument, that is, the change in the magnetic field causing a divergence of 1° from the fixed angle between the magnetic axes of the magnets, depends upon the magnitude of the fixed angle. Thus the value of this angle may be adopted according to the requirements of the particular problem in hand. The magnets finally adopted as a result of the experimental work were the disk type of very thin magnet steel.

In the model best suited for land work the magnets are damped electromagnetically by copper dampers; liquid damping has been used in other models, particularly those intended for use at sea. The magnets for the instruments constructed are mounted either on pivots with agate jewels, the centers of gravity being some distance below the point of support, or in double-pivoted suspensions. It is planned also to use quartz-fiber suspensions to reduce friction of pivot supports. The main features of the instrument may be summarized as follows: (*a*) Maintenance of a fixed relation between the axes of the magnets or magnet-systems making possible, in connection with (*b*), the construction of a short-period detecting instrument suitable for rapid surveys of high precision and investigations of magnetically disturbed regions; for example, magnetic

fields in buildings, magnetic fields about iron ships, regions of local disturbance in the Earth's magnetic field; (*b*) the arrangement for readily changing the distance between the magnet-systems to obtain the position of equilibrium of the magnets on any course, thus adjusting mechanically when used on board ship for variations in the magnetic field caused by the ship's magnetism; (*c*) the disk type of magnet and the axle-mounting make possible accurate balancing of magnets or magnet-systems, thereby decreasing troublesome dynamic effects on board ship; (*d*) the arrangements of single containers making automatic provision for all expansion and contraction of the damping liquid without setting up disturbing currents; and (*e*) the optical arrangements for eliminating parallax, thus reducing uncertainties and inaccuracies of observation.

For investigations involving detailed delineation of magnetically disturbed areas and where many determinations of reasonable accuracy are required, the earth inductor and compass-variometer greatly expedite observation and make feasible detailed surveys that would be impracticable, if not impossible, with magnetic instruments of the ordinary type. The compass-variometer and the field type of inductor thus seem particularly suited for work of this character.

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IMPROVED EQUIPMENT FOR MEASURING EARTH-CURRENT POTENTIALS AND EARTH-RESISTIVITY

O. H. Gish

Although other methods have been proposed for determining the density and direction of the natural electric currents which flow in the Earth's crust, those which have thus far been put into use require two classes of measurements, namely, measurements of the differences of potential between points in the Earth taken in such a way as to yield the potential gradient, and measurements constituting a survey of earth-resistivity in the region where the potential measurements are made.

Earth-current observations heretofore have been incomplete, in that the resistivity measurements have not been undertaken. A method has been developed and is now in use at the Watheroo Magnetic Observatory of the Carnegie Institution of Washington by which it is possible to obtain a fair knowledge of the distribution of earth-resistivity, both laterally and with depth. From these two types of measurements, the density and direction of the earth-currents can be determined. The method of measuring potentials which has been in operation at the Watheroo Observatory for over two years, although modeled upon schemes previously used

elsewhere, contains some novel features which seem to be genuine improvements.

POTENTIAL MEASUREMENTS[1]

In the diagram shown, the positions where contact to earth is made were indicated by points lettered O, P, Q, M, and N. O, P, and Q are spaced at intervals of one mile on a north-south line, while O, M, and N have the same spacing on an east-west line. The character of these contacts is a matter of great importance, since electrochemical E. M. F.'s of magnitudes as great or greater than the potential differences which it is sought to measure, are almost certain to occur. At present there is little, if any, hope of either eliminating these or making them negligible, but by using suitable material and with proper installation of these electrodes the electrochemical E. M. F.'s will generally remain constant enough, so that the more rapid variations in the earth-currents may be satisfactorily measured. It is, however, desirable to have some criterion by which it is possible to determine whether the desired constancy exists. A criterion is obtained in the present installation by using such an arrangement of electrodes that for each component three separate records are obtained which are independent except for effects arising at electrode O, the common point of reference. These would introduce spurious effects of the same magnitude in all the records, whereas, variations in the electrochemical E. M. F. of any other electrode will enter only in a single record. This sort of test has already shown its worth, not only in appraising the records obtained, but also in locating the source and ascertaining approximately the cause of the disturbance. Furthermore, a nonuniformity of the field will likely manifest itself with such an arrangement.

Lead was found from tests in the laboratory to give smaller and more steady contact E. M. F.'s than any other material examined, and, furthermore, the current flowing while setting the potentiometer produced relatively little polarization in electrodes of this material. Lead was accordingly selected for use as electrodes. Another feature is the use of both overhead and underground connecting lines. Two independent electrodes are installed both at M and at P. One of these connects with the recording instrument by an overhead conductor, the other by an underground cable consisting of lead-sheathed copper conductor placed in a bituminous conduit. No difference has been observed between the records obtained from the two types of lines, except on the occasion of a few thunderstorms, when all the overhead lines showed marked disturbances, while the

[1] See, also, Gish, O. H., "General description of the earth-current measuring system at the Watheroo Magnetic Observatory," Terr. Mag., vol. 28, pp. 89-108, 1923.

underground lines were unaffected. The earth-current potentials recorded during magnetic storms have always shown pronounced and consistent variations for the two types of lines. This fact, if borne out by further observations, will be of great importance in the interpretation of earth-current records at such times.

The measuring instrument used at Watheroo, a recording potentiometer, is a distinct departure from previous practice in earth-current measurements. Heretofore some type of galvanometer has been used, having in some cases a rather low effective resistance. Records obtained with galvanometers may be affected by variations in the circuit resistance, especially that part contributed by the electrodes, interaction between the several circuits, and distortion of the electric field and polarization of the electrodes resulting from the current flowing through the galvanometer. When using a potentiometer, or null method, these difficulties are largely obviated; variations can then only affect the precision of a setting, and that but slightly for ordinary changes at the time of balance no current traverses the electrodes and, consequently, no distortion of field results from this cause; no two of the circuits through the electrodes are closed simultaneously; hence, interaction is avoided, polarization effects in a single setting are minimized by the use of the null method, and, furthermore, the order of recording may be so arranged that for most circuits the residual polarization will enter successively in opposite sense and thus be largely eliminated in an hourly mean. A feature of this method which may at first thought seem a disadvantage is the intermittent character of the record. However, changes having a duration of ten minutes or more may be followed quite satisfactorily, while to follow changes of much shorter period a more open time-scale and a less sluggish instrument than is suitable for general recording, is necessary.

This instrument, a Leeds and Northrup 12-point recorder, with specially designed circuits, prints a point on the record at intervals of 55 seconds. The width of the record sheet is 25 cm., which will accommodate a range in the measured potential differences of 80 millivolts when employing the highest sensitivity. In the instrument as now modified the paper moves at the rate of 3.8 cm. per hour. The calibration of the instrument is sufficiently constant and uniform that the potential differences may be read directly from the ruled paper with an uncertainty no greater than ± 0.2 millivolts. At 10-minute intervals the potentiometer circuit is automatically balanced against a standard cell. By suitable connections between two columns of binding posts on a panel to the left of the instrument, any one of twelve different base-lines may be used with each of the twelve possible electrode connections, thus making possible in general the use of higher sensitivities.

METHOD OF MEASURING EARTH-RESISTIVITY[1]

The method used for obtaining the resistivity of the Earth in the region where the earth-current potentials are recorded is an adaptation of the scheme first suggested by Wenner[3] and modified by McCollum[4] for use in electrolysis surveys. Four terminals to earth, or electrodes, are placed at equal intervals along a straight line. A battery and a meter are connected between the two extreme terminals, so that a measured current may be passed through the earth between these points. The resulting difference of potential between the intermediate points is measured with a potentiometer. From the current (I) and the potential difference (V) thus observed, together with the length of interval (a), the resistivity (ρ) may be determined from the equation

$$\rho = 2\pi a V/I$$

provided the distance a is large enough so that the electrodes which form the contact to earth may be considered as points at the Earth's surface. The value of resistivity thus found must, however, in general, be considered an average in which that of the earth near the line of terminals is the more heavily weighted, while the weighting diminishes with distance from this line until at a depth, or lateral distance, equal to the distance between adjacent terminals the weights have become so small that all the earth beyond this contributes comparatively little to the total effect. Thus the body of earth involved in a single determination has linear dimensions of the same order as the interval between terminals. By increasing this interval, greater depths of earth may be included, so that from a series of such measurements a fairly satisfactory knowledge of the variation of resistivity with depth can be obtained, provided the series are repeated at positions suitably distributed over the region.

The measuring circuits with instruments and the arrangement of the contact points, or electrodes, were shown diagrammatically. The contact to earth at four points (C_1, P_1, P_2, and C_2) is made by means of steel rods (⅝ inch diameter, 2 feet long) inserted generally to a depth of one foot, but in no case should the depth exceed five per cent of the distance between electrodes. The resistance of the measuring circuits arises largely at the contact with earth. This, when too large, may be reduced by inserting several electrodes at each "contact point," provided the linear dimensions of the area over which they are distributed are small compared with the distance between contact points.

[1] See, also, Gish, O. H., and W. J. Rooney, "Measurement of resistivity of large masses of undisturbed earth," Terr. Mag., vol. 30, pp. 161-188, 1925.

[3] Bull. U. S. Bur. Standards, vol. 12, pp. 469-478, 1916.

[4] Measurement of earth-currents, Elec. Ry. J., Nov. 5, 1921.

The potentiometer and milliammeter are mounted as one unit. The former has two ranges (0 to 100, and 0 to 1,000 millivolts), and the latter has five ranges (0 to 50, 0 to 200, 0 to 500, 0 to 1,000, and 0 to 2,000 milliamperes). In order to minimize polarization of the electrodes and to eliminate the potential difference arising from currents present in the Earth from other sources, a double commutator of the type used by McCollum[3] is inserted in the lines between the meters and the electrodes. One section of this commutator reverses the E. M. F. applied across the extreme electrodes; with the other the potential difference between the intermediate electrodes is rectified, so that this may be measured with the direct-current potentiometer. The commutator is mounted in a case along with three radio "B" batteries which provide a total E. M. F. of 135 volts, which is available in various subdivisions.

Numerous preliminary measurements in the vicinity of Washington, D. C., give assurance that with this method and equipment a fairly satisfactory knowledge of the distribution of resistivity, not only laterally, but also with depth, can be obtained. Thus, for example, wholly from measurements over a filled ravine and other surface observations, it was possible to construct the original profile with good approximation, as was later verified from engineer's working plans. Measurements from floats over the Tidal Basin, Washington, D. C., gave for water, by this method, values which agreed within a few per cent with standard laboratory measurements upon samples which were collected during the field operations. The depth of the water could be correctly inferred from the resistivity measurements and apparently also the depth of silt and depth to solid structure beneath this.

The extreme conditions encountered by Mr. W. J. Rooney, who during the latter part of 1925 and in 1926 has been making a survey by this method of the resistivity at the Watheroo Magnetic Observatory of the Carnegie Institution of Washington in Western Australia, brought forth the need of some improvements in the design of the commutator. A new commutator was designed by the writer, with the able assistance of Mr. C. Huff, who also supervised the construction. The current commutating part was designed to transmit 5 amperes at 1,000 volts. Ruggedness and ready portability were requirements, as well as more than ordinary mechanical precision, in order to insure good characteristics in the commutation. The commutator for the high potential circuit, as well as an automatic switch, operates in a bath of switch oil. The former is of the cylinder type, in which marble is used for insulation. Considerable care was also required to obviate serious leaks from the high potential circuits to the potentiometer circuits. Field tests under extreme conditions have not as yet been made, but under moderate conditions and when trans-

mitting 2 amperes at 1,000 volts the expectations of the designer were fulfilled.

When the intermediate terminals are situated in soils differing much in constitution, a considerable difference in contact potential may exist between them, and as a result the galvanometer used with the potentiometer is set in more or less violent vibration. Under these circumstances, the precision in the potential measurement may be considerably lowered. This difficulty has been recently obviated under extreme conditions by placing a 20-microfarad condenser in one of the lines which connects with an intermediate electrode.

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SECTION OF OCEANOGRAPHY

(Washington, D. C., April 29, 1926)

OCEANOGRAPHIC INVESTIGATIONS IN THE UNITED STATES WEST OF MISSISSIPPI RIVER, IN ILLINOIS, AND IN THE HAWAIIAN AND PHILIPPINE ISLANDS

T. WAYLAND VAUGHAN

INTRODUCTION

As soon as practicable after the meeting of the Section of Oceanography in April, 1925, I sent to all institutions and individuals whom I knew or supposed to be interested in oceanography, within the area indicated by the above title, copies of the questionnaires prepared by the Section of Oceanography of the International Geophysical Union and a statement as follows:

Biologists.—The names of those biologists who are studying organisms in their relations to the sea should be included, for instance, students of marine ecology, students of the physiology of marine organisms when the investigations are of the relation of the organisms to the medium in which they live, and students of geographical distribution. The names of those conducting purely morphological or systematic investigations of organisms without reference to marine conditions should not be included.

Geologists.—The names of those geologists who are engaged in the study of the form, origin, and history of the ocean basins, submarine earthquakes and volcanoes, and those who are studying marine processes as a basis for interpreting geological phenomena should be included.

Physicists and chemists.—The names of those investigators who devote particular attention to the physical properties of sea water, oceanic circulation, and associated phenomena, and those chemists who conduct investigations of the chemical properties of sea water and of chemical reactions which take place in sea water should be included.

The experience in getting replies was about as usual; some persons were prompt and furnished the information requested, others supplied meager information, some were dilatory, and some did not answer the requests for data. I undertook to fill out the blanks for a number of those from whom no replies were received. The data for this report are incomplete, but still they probably constitute an adequate basis for a very nearly accurate account of oceanographic activities in the western part of our country and its dependencies.

COAST AND GEODETIC SURVEY

A summary report of the work of the Coast and Geodetic Survey is included in the report of the Committee on Submarine Configuration and Oceanic Circulation of the Division of Geology and Geography. Field

work has been prosecuted by the *Pioneer* during the past year in Alaskan waters across the Gulf of Alaska between Shumagin Islands and Vancouver Island, and off the coast of southern California; by the *Guide* in Oregon and southern Californian waters; and by the *Discoverer* in Hawaiian waters. Many depths were determined by means of the sonic depth finder; and the radio-acoustic method of determining position at sea was further developed. Records of sea temperatures, with some serial vertical sections, and of meteorological conditions and collections of water, plankton, and bottom samples were made for the Scripps Institution of Oceanography.

Important Coast Survey work was also prosecuted in the Philippine Islands.

THE NAVY

An account of the oceanographic work of the Navy is included in the committee report above mentioned. During its cruise to Australia and return, the fleet did a very large amount of oceanographic work. It made records of meteorological conditions and surface temperature and it collected water and plankton surface samples for the Scripps Institution of Oceanography. It also made about 1,000 depth-soundings by the sonic method. The naval transports operating between Seattle and Panama are assisting the Scripps Institution in its investigations by supplying records of meteorological conditions and of the surface temperatures of the waters and by collecting surface samples of water.

MARINE LABORATORIES AND THEIR WORK

California.

Laguna. The marine biological station of Pomona College—biological investigations.

La Jolla. The Scripps Institution of Oceanography of the University of California—all branches of oceanography.

Pacific Grove. Hopkins Marine Laboratory of Stanford University—biological investigations, including some biochemistry and biophysics.

San Pedro. Fisheries Laboratory of the California Fish and Game Commission—problems of fisheries but no general oceanographic work.

Venice. Biological station of the University of Southern California—biological work, including biological surveys.

Washington.

Friday Harbor. Puget Sound Biological Station of the University of Washington—biological investigations.

Hawaiian Islands.

Honolulu. Marine Biological Laboratory of the University of Hawaii—biological researches.

This short list makes it obvious that there is in the territory of the United States bordering, or lying within, the Pacific, only one institution at which the ocean is studied in any comprehensive way.

INVESTIGATIONS IN THE DIFFERENT BRANCHES OF OCEANOGRAPHY

Submarine configuration, seismology, volcanology.—Although there is deep interest in the geological departments of several universities in these subjects, viz., California Institute of Technology, University of California, Stanford University, University of Oregon in the Pacific Coast states, and in other universities in the interior of the country, the Scripps Institution of Oceanography is the only institution with a marine laboratory which is cooperating in such investigations. Important work is done at the Volcano Observatory at Kilauea on the Island of Hawaii, and in the Philippines at the Philippine Weather Bureau. That there is much activity in this field is shown by the Bulletin of the Seismological Society of America; but it is scarcely enough. In this connection the names of the following should be mentioned: Dickerson, Jaggar, Lawson, Louderback, McEwen, Masó, Vaughan, Wentworth, Willis, and Woods.

Marine sediments and sedimentary processes.—A rather full account of recent publications, reports completed but not yet published, and investigations in progress, is included in the Report of the Committee on Sedimentation, Division of Geology and Geography, National Research Council. Such researches are prosecuted in the geological departments of the Universities of California, Stanford, Illinois, and Iowa, and in connection with the expeditions under the auspices of the Bishop Museum of Honolulu. Other investigations of significance to students of sedimentary processes are those on bacteria, diatoms, and the deposition of $CaCo_3$ by algae, by Becking; the growth and relations of corals to environment, by Edmondson; $CaCO_3$ deposition by organisms and the deposition of Ca and Mg from seawater, by Irving; marine bacteria and the chemical composition of Corallinaceae, by Lipman; and the rôle of calcareous algae as rock-builders, by Setchell. The only marine laboratories at which such investigations are conducted are those of the University of Hawaii, Scripps Institution, and Stanford University at its Hopkins Marine Laboratory at Pacific Grove. Of these institutions maintaining a marine laboratory, investigations of marine sediments form a definite part of the program of only the Scripps Institution. Those interested in such investigations are Becking, Blackwelder, Ed-

mondson, Faustino, Feliciano, Irving, Ladd, Lipman, Louderback, Setchell, Trowbridge, Vaughan, and Wentworth.

Physical and chemical oceanography.—Only at the Scripps Institution are investigations in these fields prosecuted according to a definite and comprehensive program. Since accounts of these researches have been given elsewhere, they will be merely mentioned here. McEwen, Moberg, and Chambers are the principal workers. Becking and Irving are conducting, at the Hopkins Marine Laboratory, researches of importance to chemical oceanography; and the studies of Thos. G. Thompson on the diffusion of seawater in Lake Washington and the effect of land drainage on Puget Sound deserve mention.

Biological oceanography.—Reference to the list of marine laboratories and to the kind of work done at them, shows that more attention is paid to the organisms found in the sea than to the sea itself or to any other feature of the sea, and it may be noted that usually the sea is not adequately studied for an understanding of the medium in which the organisms live.

Quantitative and ecological studies of marine plankton are conducted only at the Scripps Institution, where Allen, Esterly, Moberg, Dorman, and Sleggs are engaged on such work. The mathematical basis for the treatment of the statistical data has been developed by McEwen. Kincaid and Rustia report interest in plankton. Kofoid is known to be active in the study of marine proto-zoology.

Researches in physiology and ecology are carried on at most of the laboratories. The work of Becking and Irving at Pacific Grove merits special mention for the consideration these men are paying to the chemistry of seawater as the medium in which the organisms live and to chemical changes resulting from the activities of the organisms. The investigations of Moberg at the Scripps Institution are gradually yielding a large volume of accurate information on the chemical features of the seawater as related to organisms. Others engaged in physiological and ecological investigations are Allen, Child, Fisher, Gardner, Hinricks, Hilton, Hymans, Myrtle Johnson, F. R. and R. S. Lillie, S. P. Miller, Setchell, Shelford, Tilden, Ulrey, and Weese.

Among specialists on particular groups of organisms are Kofoid on protozoa; Hanna on marine micro-organisms; Nutting on coelenterates; Edmonson, Faustino, Griffin, and Vaughan on corals; Fisher on asteroidea; Barnhart, Evermann, Jordan, Snyder, Sumner, and others on fishes; Evermann and Hanna on marine mammals. There are other group specialists from whom no reports were received, but there is question as to whether the work should be considered oceanographic. The work of Merrill on the geographic distribution of plants in Malaysia and

Polynesia is both profound and wide in its scope and is firmly tied into suboceanic topography and geological history. Hoagland's studies of kelp may be classified as chemical or biological. He has paid special attention to the selective absorption of ions.

Investigations of fisheries problems claim the attention of Cobb, Crawford, Herre, Kincaid (ostreiculture), McMillin (razor clam), Montalban, Nightingale, N. B. and W. L. Scofield, Selle, Snyder, W. F. Thompson, and H. B. Ward. Ward is studying the diseases of salmon, and Sleggs has completed a paper on cestodes and trematodes of fishes of southern California. More work on fisheries has been done than is here catalogued. Several papers of importance have been published in the bulletins of the California Fish and Game Commission and by the Department of Fisheries of the State of Washington.

CONCLUSION

This brief review reveals the lamentably small attention being paid in the western part of the United States to the study of the ocean. Knowledge of the depths of the sea is derived through the work of the Coast and Geodetic Survey and the Navy. Meteorological conditions over the sea are reported to the Weather Bureau, and records of surface temperatures are derived from a number of sources; but it appears that only the Scripps Institution is making any use of such data. Accurate work on salinity is done only at the Scripps Institution, which is undertaking the calculation of oceanic circulation, largely from data and water samples contributed by the Coast and Geodetic Survey. Vertical sections of the seawater are made only by the Coast and Geodetic Survey and the Scripps Institution. We should be thankful for all the existing instrumentalities for studying the sea; but not enough is being done to understand the great phenomena exhibited by it and to obtain knowledge of its circulation, of the interrelation of the oceans and the climate of the lands, of a medium in which geological processes of great moment are taking place, and of the medium which contains the greater part of the life on earth. Much of the work on marine organisms is scarcely marine biology, for the organisms are not considered in their relations to the sea—relations which cannot be considered until the sea is known. The quantitative study of the small organisms in the sea is confined to one place. Fishes are investigated without due consideration of the physical and chemical features of the medium in which they live and without reference to their fundamental food supply. What can be done to improve these conditions?

Scripps Institution of Oceanography.
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PHASES OF THE WORK OF THE PAST YEAR BASED ON THE NEW ENGLAND STATES, WHICH CONCERN THE SECTION OF OCEANOGRAPHY

H. B. Bigelow

Abstract.—A report on the continuance of the joint work on the north Atlantic by the Museum of Comparative Zoology of Harvard University and by the Bureau of Fisheries. A report was also made of the Bureau of Fisheries having received from the Navy a new vessel, to be renamed *Albatross II*, for this work.

Harvard University,
Cambridge, Massachusetts.

OCEANOGRAPHIC WORK ORIGINATING IN THE NEW YORK REGION DURING 1925-1926

Robert C. Murphy

Expeditions which have included oceanographic, or related field, work in their schedules during the last year are as follows:

Cruise of Mr. Harry Payne Bingham's yacht *Pawnee*.

Cruise of Mr. William K. Vanderbilt's yacht *Ara*.

Cruise of the steamship *Arcturus*, under the auspices of the New York Zoological Society.

Investigations by the writer along the west coast of South America, under the auspices of the American Museum of Natural History.

THE VOYAGES OF THE PAWNEE AND THE ARA

In February, 1926, Mr. Bingham's yacht, which is equipped with a sounding machine, nets and dredges of several types, and other oceanographic apparatus, sailed from New York for three or more months' work in Pacific waters between Panama and the head of the Gulf of California. Mr. L. L. Mowbray, of the New York Aquarium, accompanied the vessel as technical assistant. No details have been learned concerning the specific objects of the expedition, but it is known that the collection of fishes is contemplated.

During February and March, 1926, Mr. William K. Vanderbilt's yacht *Ara* visited Old Providence Island, Cocos Island and the Galápagos. Press reports, of March 31 and subsequent dates, refer to soundings and tow-net hauls to depths of "half a mile" in both the Atlantic and the Pacific, but no precise information is as yet forthcoming.

ARCTURUS EXPEDITION

The voyage of the *Arcturus* is officially designated as the "Ninth Expedition of the Department of Tropical Research, New York Zoological

Society." The *Arcturus*, originally a cargo-carrying steamer of 2,478 gross tonnage, was reconditioned and well equipped for oceanographic work by friends and patrons of the Society. Under the direction of Mr. William Beebe, the vessel was on cruise from February 11 to July 30, 1926. The regions visited comprise parts of the subtropical North Atlantic, and Pacific waters lying between Panama, Cocos Island and the Galápagos Archipelago. The staff of the vessel was as follows:

William Beebe, Director.
W. K. Gregory, Associate in Vertebrates.
L. Segal, Associate in Special Problems.
C. J. Fish. Associate in Diatoms and Crustacea.
John Tee-Van, General Assistant.
E. B. Schoedsack, Assistant in Cinematography.
William H. Merriam, Assistant in Field Work.
Isabel Cooper, Scientific Artist.
Ruth Rose, Historian and Technicist.
Elizabeth Trotter, Assistant in Ichthyology.
M. D. Fish, Assistant in Larval Fish Distribution.
Helen Tee-Van, Assistant Artist.
Dwight Franklin, Assistant in Fish Preparation.
Jay F. W. Pearson, Assistant in Macroplankton.
Serge Chetyrkin, Preparateur.
D. W. Cady, Surgeon.

Accounts of the cruise from the pen of Mr. Beebe were published currently in the *New York Times*. The only reports of a less subjective nature which have as yet appeared are a general record in the *Zoological Society Bulletin* (vol. 28, no. 4, pp. 79-116; no. 5, pp. 119-129, 1925), and a brief note by Mr. Beebe in *Science* (A Note on the Humboldt Current and the Sargasso Sea, *Science*, vol. 63, pp. 91, 92, 1926). Dr. Charles J. Fish, who was assigned to the expedition by the Bureau of Fisheries, has reported in manuscript to the Commissioner of Fisheries on the collections and observations made at one hundred and thirteen marine stations.

The original program for the strictly oceanographic work of the *Arcturus*, as communicated to the writer by Dr. Fish, was as follows:

1. A hydrographic section from the American coast through the Gulf Stream.

2. Several sections through the Sargasso Sea, one to extend from Bermuda to a point south of the Azores.

3. One month at a station in the Sargasso area, for intensive investigation of vertical life zones, for obtaining data on surface evaporation, etc.

4. Hydrographic and plankton observations in various localities—Gulf Stream, Antilles Current, North Equatorial Current, and various places throughout the Sargasso Sea.

The observations to be made at each station included sounding, at which time a sample of the bottom was to be preserved for analysis of nematodes and diatoms; color and transparency observations; vertical series of temperature and water sample collections, the latter to be titrated for salinity; surface water and air temperatures every two hours; water samples for gold and silver analysis; vertical, horizontal, and closing plankton net hauls at all levels; dredging, and trawling with Petersen young fish trawl in certain localities. In addition to this, Mr. Beebe planned to make observations on the abundance and distribution of weed in the Sargasso Sea area, the gulfweed animal communities, and the deep-sea fishes.

The program was modified considerably later, when the cruising radius of the ship was found to be much smaller than previously supposed, and the crew not sufficiently large to carry on the work laid out. The nature and location of the oceanographic work actually completed in the Atlantic is as follows:

1. A hydrographic and plankton section from 30° N. and 60° W. to a point off Cape Hatteras (36° 55′ N., 74° 12′ W., passing south of Bermuda (July 11-22, 1925).

2. A section from the Mid-Atlantic Ridge (27° 42′ N., 46° 59′ W.) to a point 100 miles N. E. of Sombrero (19° 21′ N., 61° 57′ W.), passing through a part of the Sargasso Sea, the North Equatorial Stream, and the Antilles Current (February 28-March 12, 1925).

3. Surface observations on plankton distribution in the Gulf Stream from Cape Hatteras to a point off New York (39° 24′ N., 71° 42′ W.).

4. Extensive hydrographical and biological collections from all levels at one point in the Gulf Stream, approximately 39° 24′ N., 71° 42′ W.).

5. Hydrographic and plankton data on conditions in the Sargasso Sea area at widely different seasons (February and June), to be used in a study of the seasonal variations in that region.

6. Determination of vertical life zones in the Sargasso Sea and the Gulf Stream, supplemented by similar observations in the Pacific.

It was originally expected that only a short time would be spent in the Pacific, but, after the change of plan, the following oceanographic work was carried out in connection with the visits to the Galápagos and Cocos Islands:

1. A hydrographic section from a point 200 miles off Colombia (5° 02′ N., 81° 08′ W.) to the Galápagos Islands (0° 10′ S., 90° 05′ W.).

2. Eleven vertical temperature series and nine series of vertical plankton collections in the region of the Galápagos Islands, the most southerly station being located 67 miles south of Hood Island.

3. Concentrated hydrographical and biological investigation at a point on the Coco Plateau (approx. 4° 55′ N., 86° 59′ W.) (May 25-June 3, 1925).

4. Surface and air temperatures taken every three hours.

5. Drift bottles distributed throughout entire area visited.

The objects of the *Arcturus* party as a whole had to do largely with collection and observational studies of sea life of the surface zones and of the fauna of islands visited. The Dunn diving helmet was used extensively, and cinematograph records of much of the field work were obtained. Although the cruise was designated an "expedition to the Sargasso Sea and the Humboldt Current," the leader feels that in the ordinary sense of these terms he "found neither"—the meaning of which phrase he explains in *Science* (*loc. cit.*) and elsewhere.

The *Arcturus* was in the vicinity of the Galápagos Islands during the manifestations of the most remarkable oceanic phenomena of a generation along the west coast of South America. A cross section of the true "Humboldt Current region," extending westward from the coast of Peru in latitude 6° S. or higher, might have yielded sufficient physical data to solve an outstanding oceanographic problem. No such investigation, however, was undertaken.

In his note in *Science*, Mr. Beebe mentions the absence about the Galápagos Islands, during the spring of 1925, of the usual oceanic characteristics associated with the normal flow and upwelling of the Humboldt Current. In referring to a subsequent westward-setting surface movement "as far west as the Marquesas," it is evident that the Current, which is primarily a littoral phenomenon, has here been confused with the prevailing trade-wind drift of the central South Pacific.

Parts of the marine collections of the *Arcturus* expedition have been deposited in the American Museum of Natural History.

INVESTIGATIONS OF THE AMERICAN MUSEUM OF NATURAL HISTORY IN THE HUMBOLDT CURRENT REGION

From December, 1924, until March, 1925, the writer, accompanied by Mr. Van Campen Heilner, conducted marine zoological investigations for the American Museum on the coasts of Peru and Ecuador. A report on the oceanographic phases has since been published (Oceanic and Climatic Phenomena along the West Coast of South America during 1925, *Geographical Review*, vol. 16, pp. 26-54, 1926). This paper is supplemented, moreover, by another of more popular nature (Equatorial Vignettes, *Natural History*, vol. 25, pp. 431-449, 1925).

The problem on the arid west coast of South America is highly complex. In their incipience, the factors which produce the periodical changes are doubtless purely meterological, while the end stages, because of the peculiar topography of the western watershed of the Andes, involve profound geographic effects. The intervening phenomena in the grand sequence are, however, distinctly oceanographic. The notably stable physical characteristics of the littoral ocean of this coast, and the consequently undue disturbances which occur during the rare cycles in which such characteristics are altered, are alike unequaled elsewhere. In no other part of the world does a simple reversal in direction of the coastwise oceanic circulation lead to such spectacular climatic, biological, and economic results.

The writer worked entirely from launches and other small craft, and his equipment was limited to surface apparatus. His data, therefore, do not lead to an understanding of the extent in breadth or depth of the warm counter-current which for many weeks during the winter and spring of 1925 replaced the Humboldt Current, at least at the surface, bringing about the cessation of cool upwelling and preparing the way for perhaps unprecedented rainfall along the desert coast. Even as regards simple surface temperatures, all the tables thus far obtained from the pertinent section of the Pacific, record conditions only along coastwise tracks, within a few miles of shore. The data urgently needed are routine observations made at right angles to the trend of the coast, and extending for a thousand miles or more along any parallel between the equator and latitude 30° S. Such data, especially if accompanied by subsurface records, might reveal whether the counter-current known as El Niño was in the nature of a restricted coastal tongue or whether the phenomenon represented a surface movement of colossal extent in the wake of retreating high-pressure areas. A search for figures which may throw light upon this question is now being made, with the aid of Dr. Littlehales, of the U. S. Hydrographic Office, and of several cooperating friends in South America.

The precipitation on the coast of Peru during 1925 has been recorded as certainly the heaviest since 1891; but there are reasons for believing that the conditions have not been paralleled during the course of at least six centuries. Prior to March, 1925, for example, the mud walls of the prehistoric fortress of Chan Chan, near Trujillo, still bore clearly the ancient reliefs and hieroglyphics of their builders, but the rainfall of a few subsequent weeks entirely obliterated them. The destruction of life in the sea, through a process which the writer has elsewhere described, was also unprecedented within human memory. Under date of January 30, 1926, Mr. Francisco Ballén, Director of the Peruvian National Guano Administration, writes that probably two-thirds of the sea-bird popula-

tion of the Peruvian coast, as existing in December, 1924, perished during the following months of unfavorable oceanic conditions.

Fortunately, the serious economic effects of the counter-current and its sequelæ have simplified the study of meteorological and oceanographic problems by encouraging the recording of precise data. Through the interest of the American Ambassador in Lima, of Major Otto Holstein, of Trujillo, and of other friends and correspondents in the service of numerous Peruvian industrial organizations, tabulated records of the climatic and oceanic régime are now being received regularly. These are deposited in the files of the American Geographical Society of New York, and their subsequent interpretation cannot fail to go far toward illuminating our faint understanding of one of the most remarkable geographic phenomena of our time.

American Museum of Natural History,
New York City.

PHASES OF OCEANOGRAPHIC WORK ORIGINATING AT THE CITY OF WASHINGTON AND IN THE SOUTHERN STATES, 1925-1926

W. J. Peters

In reviewing the oceanographic activities of organizations in Washington City and in the Southern States, one is concerned chiefly with certain government bureaus that maintain fleets, the Smithsonian Institution (also a Federal organization), the Dry Tortugas Laboratory and the Department of Terrestrial Magnetism, both of the Carnegie Institution of Washington. As detail is beyond the scope of this report, mere cursory mention of the work or publications will be attempted. The actual field work in many cases has already been, or will be, discussed by other papers in the symposium, although the origin may have been in Washington, where also the results are published.

Under title of "International Ice Observation and Ice Patrol Service in the North Atlantic," the U. S. Coast Guard publishes annual bulletins containing valuable records of iceberg observations, meteorological observations, soundings, surface-water temperatures and salinity. The bulletins for the seasons of 1924 and 1925 contain descriptions of and results obtained with the salinity apparatus designed by Dr. Wenner, of the Bureau of Standards, especially for rapid and accurate determinations at sea. The actual field of oceanographic operations lies beyond the limits assigned to this report.

The Bureau of Lighthouses is not engaged in original research work in oceanography, but has cooperated with other government bureaus and private institutions by making special observations on ocean currents and

surface temperatures at various lightships. The results are not published by the Bureau.

A résumé of the U. S. Coast and Geodetic Survey oceanographic operations by Captain Parker is as follows:

"Our activities in the region off the coast of the Southern States during the last year in the line of oceanography have been limited to offshore hydrography in the vicinity of Cape Fear River, North Carolina, and on the coast of the Virgin Islands of America. The oceanography work in the vicinity of Cape Fear River has been an exploration of the coastal waters seaward to a depth of about 100 fathoms by the Survey ship *Lydonia*. This work is but a part of the Bureau's project to survey the entire Atlantic and Gulf coasts of the United States in considerable detail, that is, by sounding lines closely spaced, out to a depth of somewhat over 100 fathoms. At present this work on the South Atlantic coast has been accomplished from Winyah Bay, South Carolina, as far southward as Daytona, Florida, and also off Cape Fear, North Carolina. The *Lydonia* is now filling the gap between these two surveys.

"In the West Indies, the Survey ship *Ranger* has just completed a survey of the coastal waters of the Virgin Islands, St. Thomas, St. John, St. Croix, and the small keys adjacent thereto and is exploring the shoals between the Virgin Islands and Porto Rico. In the vicinity of the Virgin Islands, the surveys have been carried off shore to depths of 400 to 500 fathoms.

"In addition to their surveying operations, the party on the *Lydonia* has been experimenting with a new type of echo sounding apparatus devised by the Submarine Signal Company of Boston, and has proved that this apparatus can measure depths with a very high order of precision, even in shallow water. That party has taken hundreds of soundings in depths from 10 to 200 fathoms which agreed with lead line and machine soundings within the probable error of soundings taken by such apparatus. Some difficulties have been encountered because this apparatus was not originally designed for use on small vessels, but these difficulties are rapidly being overcome, and we have every reason to hope that we will shortly substitute this rapid, economical means of sounding for some of the older methods.

"We are now constructing radio acoustic ranging apparatus for the *Lydonia* and expect during the coming summer to fix the geographical position of our soundings by this method, as we have been doing for the last two years on the Pacific coast. We anticipate that we shall have some new problems to solve, due to the fact that this apparatus has not been used heretofore in shallow water such as obtains along the Atlantic coast of the United States; but we believe these problems can be solved and we are hopeful that by next fall we will be locating soundings on the

Atlantic coast with the same high degree of precision that we are now getting on the Pacific coast.

"This, in brief, sums up our activities on the southern Atlantic coast. We have, of course, been doing considerable in-shore hydrography such as a resurvey of Tampa Bay and several of the sounds and inlets along the south Atlantic, but I take it that these activties do not come strictly within the scope of oceanography."

The work of the Bureau of Fisheries in the region covered by this report is limited to the study of conditions, such as temperatures, currents, sea bottom, etc., favorable for the propagation of oyster culture along the coasts of Texas, South Carolina, and Georgia. Details appear in the Fisheries Service Bulletins. In other regions special temperature and current observations have been made in cooperation with other organizations.

Oceanographic results obtained within the year on vessels of the U. S. Navy are given in the following résumé by Dr. Littlehales:

"Investigation and disproof of reported shoal soundings in charted depths of 100 to 400 fathoms off the coast of North Carolina by the U. S. S. *Nokomis*, November 1925. Sonic soundings from Cape May to Hampton Roads (on the continental shelf) by the U. S. S. *Hannibal*, December 1925. Sonic soundings in the eastern borders of the Bahama Islands by the U. S. S. *Milwaukee*, July 1925.

"Although much work of this nature has been performed in the Caribbean Sea and the West Indies, and in the Pacific, the above mentioned are all the items with which I have been connected in the region specified."

Oceanographic work by members of the Smithsonian Institution include: Miss Rathbun's monographic account of the spider crabs which appears as Bulletin 129 of the U. S. National Museum; continuation of their respective studies of amphipod and isopod crustaceans by R. Shoemaker and J. O. Maloney; the studies of various groups of echinoderms and more particularly the recent crinoids by Austin Clark; the study of marine fishes by B. A. Bean; systematic work on the unrivalled collection of cetaceans in the Museum by G. S. Miller; a report by A. B. Howell on the myology and osteology of the Asiatic finless porpoise based upon collections made during the National Geographic Central China Expedition; a report by L. Stejneger on the fur-seal industry of the Commander Islands.

The oceanographic activities of the Smithsonian Institution are sometimes involved with those of other organizations.

A systematic ecologic study of the decapod crustaceans was made by W. L. Schmitt during a short sojourn at the laboratory of the Carnegie

Institution of Washington at Dry Tortugas. Also, during a visit to the same laboratory, P. Bartsch, in addition to his systematic work on marine mollusks, exposed 1,600 feet of undersea film with his submarine cinema camera with a view to studying and showing variation of habitat and adjustment of organisms to ecological conditions. A. Mann of the Smithsonian Institution also spent four weeks at the Tortugas Laboratory during which diatom flora were studied and one hundred samples were shipped to Washington for research. They represent a practically complete collection of diatoms living in the vicinity during the month of June.

The activities of the Dry Tortugas Laboratory tend to center at present upon two problems. The first is, in a broad way, the problem of the nature of specific difference, being attacked independently by Bartsch, Graves, Tennent, and Wilson. The second is the problem of specific adaptation to natural environment, on which Longley, Schmitt, and Taylor are working. A number of papers by different authors on various biological aspects of oceanography have been published by the Dry Tortugas Laboratory during the year past, among which are: Volume III of the papers from the Department of Marine Biology of the Carnegie Institution of Washington; Taxonomy of the Amebas with Descriptions of Thirty-nine New Marine and Freshwater Species, by A. A. Schaeffer; Study of the Skull of a Fossil Sperm-Whale, and Additions to the Tertiary History of Pelagic Mammals on the Pacific Coast of North America, by Remington Kellogg.

Oceanographic work of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington has been restricted during the past twelve months, principally to reductions of sea observations, investigations of the results, and publications relating thereto.

Reduction of atmosphere potential-gradient observations made on the cruises of the *Carnegie* to a common epoch 1918.5 shows that it is feasible to construct iso-electric charts for the greater portion of the world. Important conclusions regarding potential gradient, ionic content, and radium emanation over the waters of the globe have been formulated by S. J. Mauchly. Investigations of secular variation of magnetic elements by H. W. Fisk and J. P. Ault show the urgent need of additional data over the oceans. In cooperation with the *Maud* Expedition, valuable data in terrestrial magnetism and atmospheric electricity were collected at the winter quarters, 1924-1925, four miles north of Bear Island, off the Siberian coast. Volume V of the Researches of the Department just published contains the results of cruises made on the *George B. Cluett*, a schooner chartered from the Grenfell Association in 1914, and those

made on the *Carnegie* from 1915 to 1921 inclusive, besides papers of oceanographic interest by various members of the Department.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

WORK CARRIED ON IN THE PAST YEAR BY THE BUREAU OF STANDARDS IN THE DEVELOPMENT OF INSTRUMENTS FOR USE IN OCEANOGRAPHIC INVESTIGATIONS

H. C. Dickinson

Abstract.—An informal talk on a few items of interest in the work of the Bureau of Standards, and a few suggestions as to possibilities for the future in the development of oceanographic instruments.

Bureau of Standards,
U. S. Department of Commerce,
Washington, D. C.

OCEANOGRAPHY FOR THE ICE PATROL

Edward H. Smith

Inasmuch as this is the first paper that has been placed before a meeting of the American Geophysical Union by the International Ice Patrol on the subject of oceanography, it will probably not be out of place first to touch briefly upon the history of the Ice Patrol Service. The Patrol was established by an international conference of maritime nations held in London in 1913; one of the problems before the conference being to devise some method whereby life on the North Atlantic should be more carefully guarded against the danger every spring of drifting Arctic ice. The *Titanic* disaster (April 15, 1912) was still fresh in the minds of the public and this without doubt was a great influence moving the London convention to recommend that a continuous vessel patrol be maintained in the ice-infested waters southeast of Newfoundland during the months of April, May and June. The United States eventually undertook the task of providing for such a service and, with the exception of the two war years 1917-18, it has been functioning successfully ever since.

Our government is being reimbursed each year for the expenses attending this humanitarian work by the principal maritime nations of the world, the total bill being apportioned around in accordance with the distribution of ocean-going tonnage. The directive policies and administration of Ice Patrol matters are delegated by executive order to an Inter-Departmental Board consisting of five members. The chairman is Rear Admiral F. C. Billard, Commandant of the U. S. Coast Guard; and it is this branch of the Federal government upon which devolves the duty

to furnish men and ships for the work. The Ice Patrol has two main aspects, viz., (1) the practical task of locating all ice threatening the steamship tracks, and the disseminating of this information to shipping, (2) the making of such scientific observations and investigations as will lead to a better understanding and administration of the practical work. It was early realized that the Patrol could not give its best efforts to shipping unless a carefully planned scientific program was begun from which conclusions of practical value might be drawn. Dr. Henry B. Bigelow, of Harvard University, was invited to become an honorary member of the Inter-Departmental Board and his services from the outset in a technical, advisory capacity have been invaluable in shaping the course and policies pursued since 1913. Energies directed along the general lines of investigations in both physical oceanography and meteorology have always offered a rich return of useful information; but the Patrol has had difficulty in attracting individuals, in this country at least, who possessed the particular qualifications requisite to head active investigations. The Coast Guard, therefore, during the past few years has encouraged its own officers—one especially—to improve themselves in a scientific way, wisely realizing that the Ice Patrol will give the most efficient economic service to shipping only when useful, scientific methods are employed to support the practical work. Every year the Coast Guard publishes an Ice Patrol Bulletin, consisting of some fifty to one hundred and fifty printed pages and containing a complete report of the work carried out during the current ice season. Parts are devoted to subjects such as ice scouting, the behavior of the ice, and detailed notes and discussions of a meteorological and an oceanographical nature. The pamphlet is well illustrated with photographs, sketches, and charts, and gives considerable space to a discussion of the circulation of the waters patrolled by the ships—a region of the North Atlantic than which none is more interesting in its hydrographical phenomena.

A review of the scientific activities over the period which has elapsed since Ice Patrol inauguration shows that during recent years especial emphasis has been placed upon the practice of physical oceanography. If we trace events more in detail, we observe that explorations downward in the waters of the Labrador Current and the Gulf Stream were begun by the Patrol as early as 1914; but aside from collecting and publishing the data nothing was done until 1921. That year a definite program of physical oceanography was put into effect by the Inter-Departmental Board and attempts were made for the first time to draw lessons of practical value from the material collected. The following year marks another advance, when an individual familiar with both the technical and the natural problems of the Patrol remained continuously in the ice regions, transferring from ship to ship, as each one in turn exchanged

sea duty for a relief in port. In 1922, a more intensive application of oceanography was entered upon when both ships were equipped with instruments and gear in contrast to former years when only one of the vessels had been able to carry out sub-surface investigations. Oceanographic work has been pursued since that time along plans as laid down from year to year. It may be surprising to learn that the Ice Patrol to date has collected some 3,000 sub-surface observations of salinity and temperature in the waters south and east of Newfoundland. The basis of evidence in drawing conclusions is mostly in the form of salinity and temperature distribution at various levels, and as checked wherever possible with the drifts of icebergs, some of which the Patrol has followed for weeks at a time in journeys as great as four hundred miles. Now we are beginning to see more clearly, as a result of such a compilation, the general scheme of circulation (and its seasonal processes), from St. Johns southward over the Grand Banks and off-shore into the Atlantic basin, past the slopes of which skirt the northern waters of the Gulf Stream. Discussions in detail, and conclusions, are contained in the reports of the Patrol for the years 1922-24, Bulletins 10 to 12, inclusive. This knowledge, it is worth noting, forms the principal guide upon which the Patrol vessels base their plans of scouting and also their dissemination of advice to shipping. In 1924, the Coast Guard, desiring to secure the greatest advantages offered by recent developments in oceanography, sent one of its officers to take a course of study and research with Professor B. Helland-Hansen at Bergen, Norway. The Ice Patrol material was treated at Bergen to dynamic calculation, especially that material which had been collected from around the Tail of the Grand Banks where the Labrador Current and the Gulf Stream meet. This is without doubt one of the most interesting areas of the entire North Atlantic, containing as it does some of the greatest hydrographical extremes to be found anywhere in the world. As a result of the investigation five different types of interaction between the two mammoth currents have been ascertained. Besides doing the statistical work the Coast Guard had another object in view in sending a representative to Europe which can best be described by the following remarks:

One of the most important natural problems which has confroned the Ice Patrol has been the securing of advance information regarding the probable drift of ice after it arrived at the gateway to the Atlantic (the vicinity of the Tail of the Grand Banks). If we glance at a general map of the northwestern North Atlantic, we may trace with a pencil southwards along the continental slope from Baffin Land to the Tail of the Grand Banks, without great change in direction for a distance of 1,800 miles, the general course followed by both the current and the ice stream. The cold Arctic water in it is discharged past the Tail of the Grand

Banks being no longer preserved by the general trend of the continental slope, is forced to meet directly the easterly moving masses of, or associated with, the tropical Gulf Stream. It is at this point that the course of the current, and likewise its freight of drifting ice, is subjected to great variations in direction. It is naturally extremely important information to the Patrol (for dissemination to shipping) whether the ice will be deflected northward again into the shallow shelf waters, or whether it will be swept southward across the North Atlantic Lane Routes, which in the latter case creates a grave menace to navigation. If the Patrol had knowledge of the drift tracks which bergs would follow after arrival at the gateway to the Atlantic, much more detailed information could be furnished to approaching vessels, especially during the protracted periods when fog enshrouds this cold water region. It has been found that the drift of nearly all bergs is primarily controlled by relatively deep-seated ocean currents and that the effect of the winds, such as those which usually prevail from April to July in this region, is practically nil. A monthly current map (for oceanic circulation does not fluctuate so rapidly as does the atmospheric) of this critical area where the Labrador Current and the Gulf Stream meet, is an indicator of the courses the ice will tend to follow. It is just herein that modern methods of oceanography as taught and employed by Helland-Hansen, and a few other European oceanographers, have a practical application for this particular problem confronting the Ice Patrol.

That part of oceanography upon which Helland-Hansen and Nansen are laying great emphasis these days, has a foundation which really goes back to the dynamic laws for the air and the water as brought out by Bjerknes in 1910. The feature of their methods centers chiefly upon the manner in which Bjerknes' formulæ of free motion have been developed into a form extremely applicable to the sea. Helland-Hansen, it is safe to say, has achieved more success in this line than any other one oceanographer. He and Nansen are at present bringing out a work on the eastern North Atlantic which employs these methods almost exclusively. The course of lectures as given at the Geophysical Institute in Bergen deals with an introduction to the general schemes of circulation as illustrated in various sea basins; the causes of ocean currents; hydrodynamics; Bjerknes theory; and the methods found best to illustrate calculated motions. The arrangement and development of subjects has been well considered so that if we have given the temperature and salinity from several known depths at stations scattered netlike over an ocean area to be surveyed, then the direction and the velocity of the currents are easily calculated and mapped. Several current maps for the ice regions have thus been drawn proceeding first through the preliminary steps of computing the dynamic depths of the selected

isobaric surfaces. In this connection it may be remarked that the direction and velocity of the currents as drawn on these maps agree very closely with the direction and the rate of drift of the ice as observed by the Patrol quite independently in the same region and at the same time. This method of so called "dynamic oceanography" provides an easy and efficient method for mapping currents over extensive ocean surfaces, a feature which is bound to guarantee a great employment of it in future hydrographical surveys. Coast Guard Bulletin No. 14, soon to be received from the printer, contains a simple exposition of the foregoing methods written primarily for the furtherance of the Ice Patrol work.

The program which it is hoped will be carried out this season, the first data from which are now being collected as this paper is being written, will consist of a maximum number of oceanographic stations distributed over the water south of Newfoundland which the icebergs soon will commence invading. In order that the work may be carried out in a minimum of time (for oceanographic work on the Patrol is secondary to that of ice scouting), the survey is based on a series of lines of stations running off-shore in a direction normal to the general trend of the Grand Bank slopes. Stations are being taken every 20 to 30 miles apart and extended off-shore from the edge of the Newfoundland shelf for a distance of 60 to 150 miles. The interval between lines of stations averages 100 miles, and the first line is taken on the southwest slope of the Bank beyond a point at which the ice is turned in its course. The station lines follow eastward at intervals along the continental slope and thence northward as far as time permits. It is hoped from the data collected in this manner to keep an up-to-date current map on board the Patrol ship and thus be able to foretell the paths which icebergs will follow after arriving near the juncture of the Labrador Current and the Gulf Stream. The success or failure of forecasting by such a program as outlined, depends to a great extent upon the rate at which variations take place in courses of the currents. Obviously, little reliability can be attached to a monthly current map if important changes occur in the circulation from day to day or week to week; but investigations made at Bergen with the Ice Patrol records of previous years would indicate that the alterations in direction and velocity of the current take place so slowly that the dynamic topographical maps (current charts) will be reliable up to two or three weeks. Several interesting discoveries were brought out in the course of the research work at Bergen last year, a few of which we may allude to briefly here. The famous "cold-wall" which is so clearly delineated along the entire American coast and which extends with marked clearness just south of the Grand Banks does not denote the boundary between the Gulf Stream and the variable counter set inshore as is commonly supposed. The

change in direction of flow on the contrary is located at the density-wall, and this phenomenon, it was found, lies 20 to 30 miles inshore of the famous cold-wall, near the Grand Banks. This is a feature which deserves considerable attention and future thought. It may be a hydrostatic phenomena attributable to the cold inshore (and relatively fresh water), salting faster than it warms; but in any case it results in a voluminous amount of the icy water of Arctic origin flowing in the same direction and parallel to the Gulf Stream. The dissimilarity, too, between the position of the cold-wall and density-wall, more or less confounds a view heretofore held by many that an intensive sinking (Cabbeling) of the water (especially from the Arctic) is constantly taking place along the length of the cold-wall. Further, the belief is not tenable that the Labrador current dives beneath the Gulf Stream, for as a matter of fact the edges of these two currents have about the same density where they meet. The resulting mixture it is true (as proved by hydrographical tables) is denser than either one, but even this can cause no actual sinking of the water particles while steady conditions prevail, because our rotating earth relegates free movements solely in a lateral direction and making an angle of ninety degrees with the density gradient. The extent to which this influence of so-called cabbeling reaches, of course, can be greatly magnified through alterations in the acceleration of water masses, and in such a region as south of the Grand Banks where intensive mixings and interactions are in process, dynamic laws such as specified by formulæ must be applied with qualifications. This is a subject which is worthy of an oceanographer's attention.

Perhaps it would be of interest to mention an apparatus now in operation on board the Ice Patrol ships which furnishes a practical shipboard method for the immediate determination of the salinity of water samples. The instrument is housed in a cabinet of convenient size and permits an unskilled operator by a principle based upon the variation in the electric conductivity of sea water, quickly and accurately to determine the salinity of a given sample. The final design of this successfully operating instrument is due to Dr. Frank Wenner, U. S. Bureau of Standards, who plans to publish in a forthcoming issue of an American instrument journal a detailed account, with illustrations, of the apparatus. Those who may be interested in the actual operation of the instrument under shipboard conditions are referred to an account in U. S. Coast Guard Bulletin No. 12, for 1924.

One of the two Ice Patrol ships, the *Tampa*, is equipped with a sonic depth-finder such as used in the U. S. Navy and as designed by Dr. H. C. Hayes. Primarily, it was placed on board in order that experimental tests might be carried out on locating the position of icebergs by submarine echo. It was thought that an adaptation of the device might

serve as an iceberg alarm for trans-Atlantic steamers. In addition to such experiments, a secondary program has been formulated whereby a formidable compilation of hydrographical soundings will furnish the material for revising present bathymetrical charts long known to be inaccurate in the Grand Banks region. Last year was the first time that the sonic was used by the Patrol. An account of the results obtained is carried in Coast Guard Bulletin No. 13, for 1925.

The writer in the course of the past two years has had an opportunity to meet many oceanographers in Europe and also was able to attend the annual meeting of the International Council for the Exploration of the sea in 1924. One cannot fail to be impressed with the thought, time, and money which is being devoted to the subject of physical oceanography abroad. Energy directed along such lines is prompted no doubt by a shrewd, long-sighted policy of fisheries conservation, but this stimulation of thought on oceanographical subjects, regardless of its causes, has developed and cultivated a point of view in a wide scientific circle, the parallel of which does not exist in the United States as yet. It must generally be admitted that in America we have slighted lamentably the practice of physical oceanography. This neglect appears strikingly when we turn to the list of attainments in contemporary sciences. It is all the more gratifying at this time to learn, therefore, of activities such as are reported for example by the Scripps Institution at La Jolla on the Pacific coast. Various suggestions for a program with the character of a systematic undertaking applied to the Atlantic waters along our eastern shores, come rushing to mind. The Ice Patrol unofficially, we might add in closing, has had under advisement for some time a possible expedition which would carry out a sub-surface investigation of the waters along the American continental slope from Newfoundland northward into Baffin Bay. The principal incentive, of course, is the desire for a complete history of the behavior of ice from the time it leaves the Greenland glaciers until it finally melts in the warm off-shore waters of the Atlantic basin.

The American Geophysical Union, by stimulating thought, coordinating efforts, encouraging interest all along oceanographical channels, is placed today in a most influential, responsible position.

U. S. Coast Guard,
Washington, D. C.

RECENT DEVELOPMENTS IN ACOUSTICAL DEPTH-FINDING APPARATUS

HARVEY C. HAYES

Various methods and means for determining ocean depths by sound waves have been developed during the past few years, most of

which have certain specific merits, but no one of which operates entirely satisfactorily over the whole depth range. Depths less than about one hundred fathoms are measured with considerable accuracy by any of three types of apparatus developed respectively by Dr. Alexander Behm of Germany, Dr. M. Langevin of France, and by the Submarine Signal Corporation of Boston, U. S. A. All three types register the depth in terms of the time of sound transit to the sea bottom and return by flashing or deflecting a spot of light on a scale.

During the past year the Navy has developed two distinct types of depth-registering devices which, in addition, are able to record the depth and to sound an alarm when the ship passes over any predetermined depth to which the apparatus is set. But all of these registering and recording devices fail at the greater depths because the intensity of the echo then becomes so weak, compared with that of the local disturbing noises produced by machinery, propellers and slapping of waves, that sufficient amplification to operate the relay or other deflecting parts of the apparatus cannot be secured by amplifiers without, at the same time, amplifying certain components of the intense local sounds to the point where they also operate the recorder. Thus far no depth registering or recording apparatus has been perfected that will operate reliably in depths much greater than one hundred fathoms.

The intensive research in submarine acoustics which the Navy has carried on during the past nine years has demonstrated that, on shipboard at least, the ear is greatly to be preferred to any mechanically registering or recording device because of its comparative high sensitivity and because it can take into account only such of the numerous received sounds as apply to the purpose at hand. The ear can detect the faint echo of a sound signal of definite known pitch in the midst of numerous intense local noises when other receivers would fail to register anything but these intense local sounds. It is for this reason that practically all the sound-detecting and direction-finding devices, as well as acoustical range-finding devices, developed by the Navy have been designed primarily as aids to the ear. And until some sound-registering or recording device having far greater sensitivity and selectivity is perfected, we believe the most promising line of development of depth measuring, or other apparatus depending upon the reception on shipboard of submarine sound signals, will make use of the ears for receiving the sounds. Under such conditions the depth must be determined by apparatus that can be adjusted to give to the sound signals some particular characteristic or condition that is affected by the depth and that is recognizable by the ears.

Our researches have shown that the simultaneous arrival of two like sounds, one at each ear, can be judged to within one one-hundredth

thousandth of a second and that for two unlike sounds of approximately the same intensity such judgment can be relied upon for an accuracy to within a hundredth of a second. The great gain in accuracy given by the use of like sounds is due to the fact that the binaural sense then operates to give the listener a sense of direction. This sense is entirely lacking when the two sounds are unlike. The Sonic Depth-Finder was designed to give a sounding in terms of the adjustment of apparatus required to make two like sounds arrive simultaneously at the two ears because the accuracy of such a binaural adjustment even when roughly made, would be sufficient to give the depth with a very high degree of accuracy. In practice, however, it proved that change in depth during the signal interval and variation in the speed of the transmitting cam-wheel are sufficient to prevent the operator from adjusting the two signals sufficiently near to simultaneity to bring the binaural sense into play except under very favorable operating conditions such as are given by smooth sea surface and practically level sea bottom. In general, the accuracy of adjustment to simultaneity of the two sets of signals was found to be even less than that given for two dissimilar sounds, because, in the process of adjustment, as soon as the two sets of signals begin to overlap they tend to coalesce so that their ends become blurred and it is impossible to judge with great accuracy when the signals are superimposed length for length. It proved that an experienced operator can make a depth determination accurate to within about plus or minus five fathoms.

An error of five fathoms is not a serious matter for depths greater than about a hundred fathoms—the range over which the sonic depth finder is capable of operating—but for depths under one hundred fathoms it becomes necessary to obtain greater accuracy. Somewhat over a year ago the Naval Research Laboratory undertook the problem of developing an acoustical depth-finder that would cover the whole range of ocean depths and give a higher degree of accuracy than the original device, which originally was developed for a range-finder and not a depth-finder. This problem has been fairly well solved; and its solution represents the only progress made in acoustical depth-finding apparatus during the past year that has come to our attention.

The new device employs the same procedure on the part of the operator as does the sonic depth-finder, which consists of adjusting the apparatus so as to cause two systems of equally spaced signals to arrive simultaneously at the two ears. Except for this one similarity, the principle of operation of the new device differs radically from that of the old one. The old device employs the same pitch for both sets of signals and brings them to coincidence at the ears by adjusting the period between signals, so that the time of sound transit to the sea

bottom and return shall be a whole multiple of this period. The new device employs a decidedly different pitch for the two sets of signals. It does not vary the periodicity of the signals, but instead provides means for generating the comparison signals at any desired instant after the generation of the submarine sound signals. By this means the comparison signals can be delayed behind the sound transmitter signals so that they will energize one phone of a double telephone head set at the same instant that the echo of the submarine sound signal is picked up by a submarine sound receiver and heard in the other phone. The time of sound transit to the sea bottom and back is then equal to the known time the comparison signals are delayed behind the sound signals. Such an arrangement permits the adjustment to simultaneity to be made for any depth independent of the length of the sound signals, but the original device only permits such adjustment for depths beyond which the time of sound transit is greater than the duration of the signals, thereby rendering it useless for depths of less than about twenty fathoms.

The use of a distinctly different pitch for the two sets of signals not only removes most of the coalescing and blurring troubles experienced when like signals are used but, strange to say, permits the use of the binaural sense in making the adjustment for simultaneity so that this adjustment can be made with a high degree of accuracy. The explanation of this unlooked for result appears to be simple and is as follows: Two pure sounds of slightly different pitch are near enough alike to cause the binaural sense to operate and give a sense of direction. This is readily proved by holding two tuning forks of slightly different pitch at the two ears respectively. If the higher pitched fork is held at, say the right ear, the sound appears to the listener to come from his left and to move across to his right and these excursions continue periodically, the period being equal to the beat period given by the two forks. These excursions become more rapid as the pitch difference between the forks becomes greater and appear to vanish when their frequency becomes something like fifteen or twenty per second, or in other words, when the period between beats is of the same order as the time interval of vision persistence. When the beats occur so rapidly that the mind cannot comprehend each separate excursion of the sound image, the sense of direction vanishes and the two distinct pitches are heard, one at each ear. And since under such conditions there is no unwilled effort to determine the direction of the sound, the operator is as free to listen for sound from any definite direction as he would be when the forks are silenced. If the two fork sounds of different pitch are now broken up into short dash-like signals and the listener focuses his attention for a sound, say straight ahead, he will hear a sound in that

direction if the signals reach the two ears in such a way that their first exposure together is made when the sound waves are in phase. This does not mean that the front end of the two signals reach the two ears simultaneously, but that when the later one reaches its respective ear it will be in phase with that part of the earlier signal that is already stimulating the other ear. The first binaural exposure will then be the same as that given by a sound source dead ahead and if the listener's attention is focused for a sound from that direction he will have a distinct impression that a sound is actually coming from that direction.

If the foregoing explanation is correct then when the two signals of different pitch are adjusted for a binaural center the greatest difference in time of arrival at the two ears will equal one second divided by the difference in the pitch of the two sounds. The average difference will be half of this value. Laboratory tests employing 1060 for the pitch of the sound signal and 1325 for that of the comparison signal have shown an actual average error from the adjustment to perfect simultaneity of the order predicted and in terms of depth soundings represents an average error of 0.8 fathoms and a maximum error of about 1.6 fathoms.

This type of depth-finder has been tested on one ship, the U. S. S. *Hannibal*, with favorable but not wholly satisfactory results, because the relative location of the submarine sound transmitter and receiver on the *Hannibal* is such that the direct sound from the transmitter energizes the receiver so strongly that it responds to this sound, which it is not desired to hear, more intensely than it does to the echoes of the signals. As a result, only soundings in shoal water, where the echoes are very intense, could be taken. However, the tests demonstrated the ability of the device to take accurate soundings to depths as shoal as six fathoms and there is all reason to believe that it will work at the greater depths when installed on a ship carrying a submarine sound receiver well shielded from the direct sound of the transmitter.

Naval Research Laboratory,
Bellevue, Anacostia, D. C.

A NEW BASE MAP FOR THE OCEANOGRAPHER

W. E. Johnson

Wherever oceanic information is exhibited in graphic form one thing is notable, and that is the great distortions of relative area and linear representation, due to the use of Mercator's Nautical Projection as a base. Instruments and methods have been devised for securing and recording data and a number of nautical organizations are co-operating in collecting it. Thus, many data are being assembled, but an adequate instrument

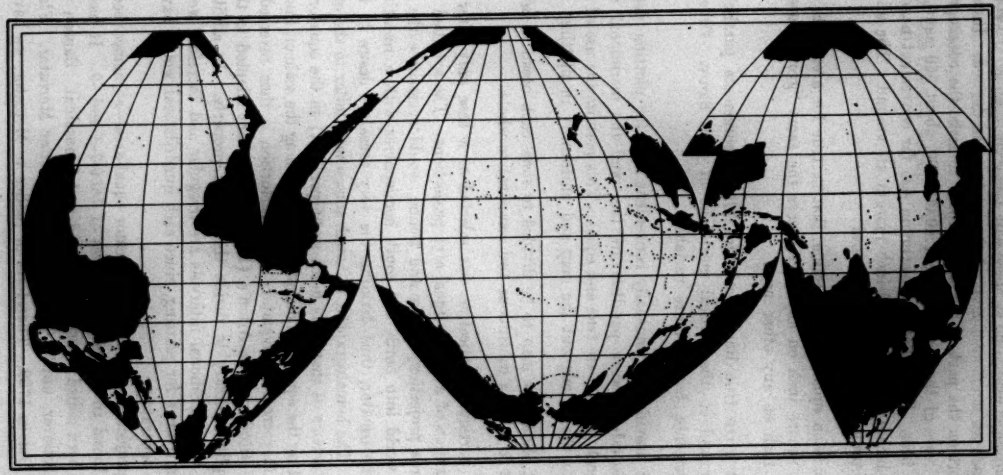

FIG. 1

The oceans of the world on Mercator equal-area projection

for the proper exhibition of these data has been lacking. To supply this deficiency an equal-area map of the oceans was devised. It represents an effort on the part of the cartographer to serve the oceanographer.

The scale of the map will be 1:40,000,000, about 550 nautical miles to one inch. This allows a maximum size for convenient handling, 22 by 44 inches, including a 2-inch margin all around. The advantages of the projection chosen are several:

1. It is an equal-area projection, that is, true for area scale throughout; a square inch on any part covers the same "ground area" as a square inch on any other part.

2. It gives true linear scale for all measurements paralleling the equator and on the vertical meridians of each figure. Other linear measurements, however, are variable.

3. It provides an unusually convenient base for plotting data, since the intervals between parallels are true and the meridional divisions along each parallel are true and equal. This permits the use of a degree scale for use throughout the map and uniformity in plotting.

4. It allows the map to be divided to show each ocean to advantage and yet to make a continuous and comparative whole.

This particular projection was selected as a base only after careful consideration of available equal-area projections. The so-called "Conic" equal-area projection, Albers and Bonne, would necessitate the division of the world into north and south hemispheres with a resulting split along the equator, thus dividing the very areas we desire to hold together. The homalographic, although somewhat similar to the one used, has distortions of shape (as much as 25 per cent) in the equatorial belt, contracting the equatorial distance and increasing the scale on the meridians as they cross the equator. This distortion is then reversed in the higher latitudes. The Aitoff's (Hammer's) is not adapted to the staggered split necessary to divide the oceans properly. In addition the parallel and meridional intervals are irregular and therefore would not be as convenient for plotting, since each quadrilateral would have to be divided separately.

The projection used is the Mercator equal-area—so named because it is first found in Mercator's Atlases of 1606-7-8 and -9. It has subsequently been called Sanson-Flamsteed and Sinusoidal. Sanson did not use it, however, until 1650, over 40 years after Mercator. Flamsteed used it first in 1729. Therefore, in justice to Mercator, we have given

it his name. That Mercator used it, evidences his appreciation of mass representation as regards relativity in contradistinction to conformality in his nautical projection.

U. S. Coast and Geodetic Survey,
Washington, D. C.

SECTION OF VOLCANOLOGY

(Washington, D. C., April 29, 1926)

SYMPOSIUM ON SCIENTIFIC CO-OPERATION IN THE ALEUTIAN ISLANDS

SCIENTIFIC CO-OPERATION IN THE ALEUTIAN ISLANDS

T. A. Jaggar, Jr.

The topic for the symposium was suggested by the immediate prospect of the founding of a volcano observatory in the Aleutian Range under the United States Geological Survey. The Aleutians are difficult of access and remain but little more explored than when Alaska was first acquired. The region of greatest interest is the Andreanof group about Atka, between the Islands of the Four Mountains and Tanaga. This region has hitherto defied all attempts at mapping, collections, soundings, and geophysical measurements, beyond the barest reconnaissance. There are here thirty unknown volcanic islands, in the latitude of southern British Columbia (52°), in the middle belt of the Aleutian arc, in a length of 350 nautical miles. The climate is mild, but windy and foggy.

For the proper conducting of all kinds of scientific investigations for years to come, about Atka as center, three things are essential; (1) the erection and manning of a permanent geophysical station; (2) the permanent co-operation of a government bureau that operates boats; (3) co-operation of several establishments, governmental or otherwise, in expense.

In this region the U. S. Geological Survey and the Geophysical Laboratory of the Carnegie Institution are interested in volcanoes; the Department of Agriculture is interested in climate, soils, biology, and forestry; the Coast Survey is interested in charts, soundings, gravity, magnetism, primary triangulation, and seismicity; the Navy is interested in Coast Guard operation, wireless, aviation bases, navigation, and oceanography; the Army is equally interested and has been located in Alaska many years; the Smithsonian and the National Museum are interested in the ethnology and natural history; the Department of Commerce is interested in lighthouses, transportation, fisheries, mining and trade; all are interested in topographic mapping, whether by air, land, or sonic sounding.

It is hoped that this symposium will develop the possibilities of a genuine cooperation.

Hawaiian Volcano Observatory,
Hawaiian Islands.

THE ALEUTIAN ISLANDS FROM THE STANDPOINT OF THE GEODESIST AND CHART-MAKER[1]

WILLIAM BOWIE

No matter what the study of a large area of the earth's surface may be, an essential factor in the successful working out of the problems and their solution is the knowledge of the geographic positions, elevations and configuration of the ground. Without such data, one works largely in the dark.

As far as the Aleutian Islands are concerned and the regions of Bering Sea and the Pacific Ocean nearby, which would be involved in any investigation covering the islands, we have scant data. It is true that the islands are shown on charts, but are they in their correct positions? The chances are that they are not. A glance at the charts covering the islands will show that beyond Unalaska Island there are exceedingly few soundings, certainly not enough to afford any idea of a detailed nature as to the configuration of the bottom of the Pacific Ocean and Bering Sea near the islands and the degree of slope out to deep water.

The approximate elevation of some of the islands has been obtained by various means, but detailed topographic work has not been done on any of them, except for the shore line of islands between the Alaska Peninsula and Unalaska Island. Very little shore-line data have been secured on the Bering Sea side of the peninsula and islands.

It would seem that it is essential to have as accurate geographic positions of the islands as may be possible, a determination of the elevation of peaks and a knowledge of the configuration of the terrain of each of the islands. All of this work could be done easily but, necessarily, it would require time and money. The days on which a surveying party can work on the Aleutian Islands are few in number because of rains and fogs.

As far as the soundings are concerned, there should be detailed soundings around each island to show the configuration of the bottom out to the thousand-fathom curve. There should be additional soundings at right angles to the axis of the chain of islands from the 1,000-fathom curve across the edge of the shelf, across any deeps that may parallel the chain, and then out into the main body of Bering Sea and the Pacific Ocean. With such information we should be able to take further steps in studying the history of the islands from the geological and geophysical standpoint.

It would be well if current surveys could be made in the vicinity of the islands with a view to learning whether the drift of water is towards or from Bering Sea or parallel to the axis of the chain. With a knowl-

[1] Read by the Secretary.

edge of the currents, we should be able to understand better the distribution of the fauna and flora.

The geodetic problems involved in the Aleutian Islands would be the determination of the latitude and longitude of the various islands, the observations for deflection of the vertical, if this is possible, and the determination of the value of gravity. The islands do not lend themselves readily to the determination of geodetic positions, except in a few cases. The customary means of determining positions is triangulation, but this involves the measurement of a base line and of the angles of triangles of which points on the islands form the apexes. Where the islands lie in groups it is possible to get well-formed triangles by means of which geographic positions can be carried with accuracy from island to island, but where the islands are strung along in a line, triangulation is valueless or almost so. Besides, errors are likely to accumulate to a great extent when long distances are covered.

Where triangulation is not possible, distances between two contiguous islands of the chain may be determined by dead reckoning with a ship. The effect of current could be largely eliminated by running the ship between the islands in both directions and then taking a mean of the distances. As a matter of fact, it might be possible to carry the azimuth through the chain of triangles just as might be done in a traverse overland. This would involve the reading of horizontal angles at each of the islands of the chain. With these azimuths and such triangulation stations as are possible and the determination of some distances by means of the ship, a fairly good location of the individual islands, might be made.

It is possible that, some day, a new method will be developed for the determination of distances between islands, which would involve the velocity of light. Professor A. A. Michelson is at present working at Mt. Wilson Observatory, on the problem of determining the velocity of light. The Coast and Geodetic Survey has measured very accurately a base for that work and Professor Michelson expects to secure an accuracy in the velocity of light redetermination of about one part in 100,000. If he does this, and if his apparatus can be easily used in the field, then it may be possible that we can use the velocity of light to determine the distances between island stations. If this method is found to be practicable, then much improvement can be made in island location over what is now possible.

If it were possible to get very accurately the geographic positions of island stations, then, by a comparison of the geographic positions determined astronomically and by triangulation or otherwise, we could get deflections of the vertical which could be used in a study of the devia-

tions from normal densities in the region surrounding each of the astronomic stations.

Although we may say that we determine by the deflections of the vertical and the value of gravity the deviations from normal densities in the material of the Earth's crust, it may be said with equal exactness that what we do is to measure the differences in weight of blocks of the Earth's crust. Of course, the use of the word "block" must not be taken literally for there is no such thing as an independent block of the crust. The crust is continuous throughout; but it is easy to form a mental picture of what is done by assuming that the Earth is made up of separate blocks with cross sections of approximately 50 or 100 miles square.

The values of gravity should be determined by approved methods on many of the Aleutian Islands and we should also obtain, if possible, gravity observations at sea such as those now being made by Dr. Vening Meinesz of the Dutch Geodetic Commission. As is well known, he has successfully determined values of gravity at sea by swinging pendulums on a submerged submarine.

With the data mentioned above, we should be able to test the isostatic condition of the Earth's crust under the islands and in the water areas contiguous to them. As far as geodetic work is concerned, this would be all that is necessary or that could, under any circumstances, be accomplished. With a knowledge of the isostatic condition of the crust, then we should be able to attack the problem of how the crust in this region is maintained in equilibrium or why it might be out of equilibrium, if the adjustment is found not to be perfect. Beyond the proving of the degree of perfection of isostasy by means of deflection and gravity stations, the geodesist cannot go. If he works beyond that point, he is operating in the field of geophysics and geology.

U. S. Coast and Geodetic Survey,
Washington, D. C.

Discussion

Prof. Brown mentioned the calculations of Jeffreys, which indicate that a large fraction of the energy dissipated by tidal friction is dissipated in Bering Sea. This is an additional reason for getting more accurate data on the currents about the Islands. Some data were collected by governmental vessels a few years ago, but have not been made publicly available.

Mr. Sargent mentioned the organized aerial photographic mapping in southeastern Alaska which is planned by the Navy for the summer of 1926, and its possible extension later to the north and west.

Mr. Sosman mentioned the hypothesis that the dissipation of tidal

energy in northern latitudes, such as Bering Sea, would give a twist to the Earth, and showed that this is not a necessary consequence, for the point of application of the resultant retarding force might be far distant from the point of absorption of the energy.

PROGRESS IN THE DISCOVERY OF VOLCANIC CRATERS ON THE ALASKA PENINSULA

R. H. Sargent

Abstract.—Mr. Sargent gave a description, illustrated with lantern slides, of two new craters on the Peninsula to the west of Aniakchak crater which was explored a few years ago. The first of the two is much smaller than Aniakchak. The second is of large size, with a higher rim than Aniakchak, and a diameter of several miles. It is at present filled with snow and ice which supply a number of glaciers on the sides of the mountain, but there is evidence that it has been active in recent times. Descriptions and maps will be published later by the Geological Survey.

U. S. Geological Survey,
Washington, D. C.

MAGMATIC PROBLEMS OF THE ALEUTIANS

C. N. Fenner

So little is actually known about the igneous rocks of the Aleutian Islands that it might seem as if there were little more to say on the subject of magmatic problems than that the whole field lies before the investigator.

That can indeed be said, and it can be said further that the region is especially favorable for investigation because of the great number of active and extinct volcanoes situated along this chain of islands; but it is possible to suggest two or three more specific problems.

The chain of the Aleutians forms part of a volcanic range of great length. To the east and northeast it is continued without interruption through the length of the Alaska Peninsula, and still farther to the northeast along the shore of Cook Inlet. The westernmost active volcano, so far as known, is situated on Little Sitkin Island, and the one farthest to the northeast is Mount Redoubt. The arrangement of the vents takes the form of a broad arc nearly 1,500 miles in length. It is fairly certain that in former times activity extended farther to the westward. Buldir is described as an eroded volcanic cone, and Attu is said to be composed of pre-Tertiary igneous rocks. Possibly at the other end there may have been a prolongation beyond Redoubt. There are at least forty vents which have been active within historic times.

A remarkable characteristic of the chain is that it pursues an uninterrupted course across the most varied terrestrial features. At its northeast end it lies among high mountains and within a region which is apparently truly continental in character; along the Alaska Peninsula it is still within the continental border, but the average elevation of the surface has become much less; in the Aleutians the volcanic islands form the summits of a narrow ridge rising abruptly from abysmal depths.

According to present ideas of isostasy, the different elevations of the regions traversed are the expression of something fundamentally different in the character of the underlying material within the upper sixty or seventy kilometers of the Earth's crust, and this line of volcanoes cuts across these features and brings up samples of the underlying material for examination. It is not possible to say from how deep a source the material is drawn, but, to judge from the great length of the line and the great activity displayed along it, the fracture probably reaches a profound depth. A study of the eruptive material in its relation to these features should give interesting information. Though there may be considerable variety of lavas extruded from time to time at any one place, still we should expect that the average product from a volcano in the western Aleutians would be of greater specific gravity than the average in the Katmai region, for instance, and still heavier than that from Iliamna or Redoubt. If no such relation is brought out, the information will still be of value, as it will indicate that the immediate source from which volcanoes draw their supply is much above the depth of compensation.

A second problem for investigation has certain points of contact with the last, but also introduces some quite different questions. It is suggested by certain work I have done on Katmai rocks.

Almost no information is to be found in the literature regarding the chemical composition of the rocks of this whole volcanic chain. We have reports of andesites, basalts, and diorites at various points, but very few analyses. To remedy this in some measure I have made analyses of eighteen specimens from the Katmai district,[1] and the results are represented on a diagram on which the basic oxides are plotted against silica. The rocks range from an olivine basalt, with about 54.5 per cent silica (calculated on a non-volatile basis), to the very siliceous soda rhyolite of the 1912 eruption, with about 77.5 per cent silica. Included in the collection are lava flows from several volcanoes, dike rocks, and plutonics. Their age probably ranges from well back in the Tertiary to the present.

[1] These analyses, and other matter relating to the Katmai region, will be published shortly in a separate article.

A striking feature of the diagram is the nearly rectilinear distribution of the constituents. It serves as a pronounced family characteristic to unite rocks of very different age, composition, and mode of occurrence. There can be little doubt that all these rocks have a common ancestry.

These rocks are from one small section of the volcanic chain. Naturally, one wonders whether the same characteristics hold as we move away from the Katmai district to the northeast and southwest; or, if not, in what manner a change expresses itself in terms of geographic distribution. Available analyses are too few to give much information on this matter. On a second diagram the results of recorded analyses have been plotted and these have been supplemented with four new analyses.

Several of the analyses fall fairly close to the lines of the Katmai diagram, but on the whole the variations are rather large, and some depart widely. A specimen from Bogoslof Island is an extreme variant. Bogoslof seems to offer, both in its remarkable behavior and in the unusual character of its rocks, an especially interesting object of study. Its lavas ought to be compared with those of the adjacent islands, which are situated more nearly along the direct line of the chain.

The character of the Katmai diagram is doubtless the expression of two factors: (1) the sort of material on which differentiation starts to work; and (2) the processes of differentiation by which changes are brought about. With similar information to that of the Katmai district obtained from several other points along the chain, we should have a much better basis than now from which to draw conclusions on both these points and on other fundamental problems in petrogenesis and volcanology.

A third problem is suggested by the simultaneous activity of Bogoslof and Augustine in 1883. In October of that year, when New Bogoslof rose from the sea, Mount Augustine became active for the first time in recorded history. Both eruptions are described as violent. At the same time two other volcanoes, probably Shishaldin and Akutan, emitted smoke and steam. There is a suggestion here of sympathy of activity, though the phenomena may represent merely a coincidence. There is a similar suggestion in the close correspondence of eruptive manifestations of Pelée and La Soufrière in the West Indies in 1902, and in the reported simultaneous activities of several Japanese volcanoes along the Kirishima zone during the violent eruption of Sakurajima in 1914. It would be of value in forming a conception of plutonic conditions, to know whether there really is, at times, sympathetic activity. A record of phenomena at vents along an extended chain, continued for several years, would give a basis from which to draw conclusions.

Most volcanological studies have been made on isolated volcanoes or small groups of volcanoes, but usually only the major manifestations

have been thought worthy of investigation and record. There are some problems, such as those mentioned, which can be much better attacked by studying the relations that different parts of a long chain bear to each other.

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Discussion

Following the two papers by Messrs. Sargent and Fenner, there was discussion by Dr. Wright and by the authors concerning the relative importance of explosion and subsidence in the production of the Alaskan craters. The evidence on the new craters described by Mr. Sargent is not yet sufficient for a final opinion. The outline of Aniakchak indicates an original cone 4,300 feet in height, and there is ash enough outside of the crater to restore such a cone. Dr. Fenner showed that the Katmai crater is due, at least in part, to subsidence. Dr. Washington cited Bolsena, Rocca Monfina, and other Italian examples of craters due to subsidence. Similar phenomena were mentioned by Brown and Washington for Kilauea, and Humphreys for Crater Lake. Messrs. Humphreys, Washington, and others also discussed the few existing data on sympathetic eruptions at far distant points.

THE NEED FOR SEISMOLOGIC OBSERVATORIES IN THE ALEUTIAN ISLANDS

FRANK NEUMANN

To the seismologist the idea of establishing a geophysical observatory in the Aleutian Islands immediately brings to mind two outstanding facts. First, it is the most neglected of any major seismic region of the world so far as securing local instrumental data is concerned; secondly, establishment of such an observatory would eliminate duplication of effort in the fields of instrumental seismology and volcanology. Just what the exact relation is between volcanoes and earthquakes, is immaterial at this time. It is sufficient to know that students in all branches of geophysics are unanimous in their support of observational projects which aim to explain this relation on a quantitative or correlative basis rather than on any other.

We are to discuss one phase of what is perhaps the most oustanding need of scientists who are studying volcanic and seismic activity in the Pacific. The Aleutian Islands region is famous for its volcanoes, its disappearing islands, and its mighty submarine earthquakes; yet, so far as scientific observation of these activities is concerned, it is practically

a virgin field. In all the world of seismology it is the classic example of neglect.

Just how do the Aleutians fit in with other seismic regions of the earth? The earthquake regions of the Pacific, when viewed on a chart, describe a great curve convex toward the north. When examined on a globe we find them to coincide closely with a great circle. These things are mentioned in order to picture the seismic regions of the Pacific as constituting a great belt of activity as distinguished from an irregular distribution. The East Indies will arbitrarily be considered part of another great seismic belt stretching westward to southern Europe. The Pacific belt may then be defined as one extending from the Philippines to the lower part of South America.

Inasmuch as we are interested in studying instrumental control in the Pacific belt, we shall divide it into four parts, approximately equal in extent. The northern limit of the Asiatic region will be the southern part of Sakhalin Island, where the most northern Japanese observatory is located, at Otomari. The second, or Aleutian region, stretches from Otomari to Sitka, Alaska. The chief characteristics of this region are great submarine plateaus beneath the Bering Sea and deep submarine troughs immediately south of the Aleutian Islands. The third region extends from Sitka to the south border of Mexico; and the fourth southward through Central and South America. Although of a very arbitrary nature, these boundaries adhere fairly closely to political boundaries and are easy to visualize because each is approximately 3,500 miles in length.

On the basis of epicenters published by the British Committee on Seismological Investigations, covering the period from 1913 to 1920, I have estimated the percentage of total seismic activity in each of the four regions as follows: Japanese region 43 per cent, Aleutian region 19 per cent, North American region 18 per cent, and South American region 20 per cent. The distribution of observatories, expressed in percentage of the total number, is, for the respective regions, 46 per cent, 1 per cent, 37 per cent, and 15 per cent. Dividing the figures representing earthquake distribution by those representing observatory distribution we get what might be termed the relative regional efficiency of our observational scheme in the Pacific, taking seismicity into account. These relative efficiencies are represented by the figures 107 for the Japanese region, 5 for the Aleutian region, 207 for the North American region, and 80 for the South American region. In other words, if we took one-half the seismologic stations in North America and distributed them over the Aleutian Islands, we would have a fairly uniform distribution of existing observatories. As it is, we have in the Aleutian region one observatory at each end and none between.

In the deeps off the Aleutian Islands we find the origins of probably more world-shaking earthquakes than in any other part of the world. If we acknowledge that seismologic stations are necessary anywhere, we cannot but recognize the very urgent need for additional stations between Sitka and Sakhalin Island.

Perhaps the greatest benefit to be derived from seismologic observations in the Aleutian region would be greater accuracy in locating earthquake epicenters in this region. Just because a determination of epicenter is published as final, one not familiar with the process may feel that all is well, not knowing that there may be a probable error of as much as fifty miles in position of origin and 20 or more seconds in time of origin. These discrepancies are, of course, due to our limited knowledge of the velocity of earthquake waves, including variations in velocity over different paths on the Earth's surface.

The nearer an observatory is to an earthquake origin, the more right we have to give its data greater weight in the final analysis because the probable errors necessarily diminish. This is important to remember because, no matter how excellent a record is obtained at any observatory, it is, in a sense, wasted effort (so far as accumulating velocity data is concerned) if we cannot determine within reasonable limits the position of origin of the earthquake from some nearby observatory.

Probably no other part of the world exhibits such wide variations in the velocity of earthquake waves as the Pacific basin; and on the evidence now available, particularly data collected at the Honolulu observatory of the Coast and Geodetic Survey, some of the greatest variations exist beneath the deeps between Hawaii and the Aleutian Islands. We find variations from the so-called standard seismological table so great that I venture to predict that in twenty-five years every first-class seismologic observatory will compile its own tables with corrections for azimuth and distance. To one who is familiar with the problem of interpreting seismograms, this seems to be the only solution; and some solution must soon be arrived at if we are to plot accurately the origins of earthquakes from instrumental data. Considering these problems of the future, the need for local seismological records in the Aleutians becomes increasingly apparent.

Dropping the problem of measuring the velocity of earthquake waves over great distances, we come to another group comprising earthquakes occurring, roughly, within a 500-mile limit. It is from records obtained within this radius that we learn something of the depths of focus of earthquakes, and also of the depths of the outer layer of the earth's crust. I shall do nothing more than touch on some theories involved in these problems, and this only because it makes clear one salient point. I will show why earthquakes of high intensity within 500 miles of an

observatory are necessary to make records sufficiently sharp to record all the phases peculiar to nearby earthquakes. Because of this requirement, a first-class observatory in the Aleutians is eminently desirable.

Imagine the focus of an earthquake to be 25 km. below the surface of the earth, and suppose the depth of the earth's outer layer to be 50 km. It is easy to picture how waves radiating from this focus can reach a nearby observatory over a straight path through the outer crust. Because of the curvature of the earth's crust, it is possible for the rays, or elements of a wave front, to reach a more distant observatory over two paths; one through the outer crust only; the other by passing downward through the outer layer into the layer beneath it and back again through the outer layer to the observatory. Thus the appearance of two phases of the same elementary wave front on a seismogram depends upon the distance of the observatory from the origin, the depth of focus, and the depth of the outer layer. Both of these phases are necessary for discussion of depth of focus and depth of layer, and they are not obtained unless the earthquakes recorded be within the 500-mile limit, for beyond this distance all of the recorded waves penetrate the layers below the outer one.

Another method of measuring the depth of focus and the thickness of the outer layer depends upon recording at nearby observatories waves which have been reflected from the bottom of the outer layer, or which have suffered several reflections between the bottom of the outer layer and the surface. Very promising results have been obtained in studies of strong local shocks in Porto Rico. Investigations of this kind could be carried on to still greater advantage in the Aleutians.

American geophysical institutions should consider it a privilege to support any project looking toward the establishment of a geophysical observatory in the isolated Aleutians, contributing, if necessary and practicable, personnel, instruments, and funds. If they are to profit by the operation of such an observatory, they should also assist in its establishment and maintenance.

U. S. Coast and Geodetic Survey.
Washington, D. C.

Discussion

Dr. Humphreys remarked on the number of seismologic stations listed in the United States, and the number that are really active. Prof. Brown inquired concerning the possibility of a seismograph which would record for several months on an isolated island, without attention. The speaker said that no such instrument is now available, as the need for accurate time-records makes very long graphs necessary. Simple records of intensity, without accurate records of time, would be useful, however.

PROBLEMS IN TERRESTRIAL MAGNETISM AND ATMOSPHERIC ELECTRICITY PERTAINING TO THE ALEUTIAN ISLANDS

J. P. Ault

Prior to 1915, magnetic observations in the Aleutian Islands were limited to 30 values at eight localities on land and 14 values at 10 localities at sea, the first observations having been made at Dutch Harbor in 1867. In 1915, the *Carnegie* made observations in the vicinity of the Aleutian Islands during her cruise up into the Bering Sea, calling at Dutch Harbor on the way north, and returning south near Attu, the westernmost island of the group. During the following year, on the same cruise, she passed near the group on her voyage across the north Pacific from Guam to San Francisco. In 1925 Lieut. G. C. Jones of the Coast and Geodetic Survey made observations at four islands of the group, establishing 12 stations, his results indicating very large local disturbances, especially on Atka Island. Three of these islands had been occupied in 1873, and the results of Lieut. Jones' observations give valuable information concerning the annual variation at the repeat stations.

Thus we see that up to the present time the magnetic data in and around the Aleutian Islands depend upon one land expedition and one sea voyage, supplemented by earlier observations scattered in distribution as to time and locality and of uncertain value, owing to the presence of local disturbances. This scarcity of observations in the Aleutian Islands has been due chiefly to inaccessibility and lack of transportation facilities. Any assumption of annual-change values in the group is based on insufficient data except at Dutch Harbor, where observations have been repeated at frequent intervals since 1867.

Owing to the presence of pronounced local disturbances due to the volcanic nature of the islands, secular changes probably will be irregular, and values of these changes as determined ashore may not be assumed to hold for localities at sea and vice versa. Investigations by H. W. Fisk at Bermuda indicate that the secular change is considerably modified in regions of local disturbance. Observations by the Carnegie Institution of Washington among the islands of the South Pacific Ocean point to the same conclusion. The Aleutian Islands will be a fruitful field for an investigation of this effect, since the normal annual change can be controlled by repeated observations at undisturbed localities on the ocean in the vicinity of shore stations which are locally disturbed. Thus there is need for repeat observations, not only on land but also at sea, throughout the extent of the Aleutian Island chain.

For the purpose of improving the conditions of navigation, both at sea and in the air, regions of local disturbance in the islands should be investigated in detail to determine their extent and amount. This group of islands very probably in the near future will form the highway over which air travel will pass between North America and Asia. The planes of the Army Air Service followed the Aleutian Islands on their flight around the world. Since these planes were equipped with the new earth-inductor compasses a knowledge of the inclination as well as of the declination was of great value. On account of the possibilities of future travel by air the distribution and variation with time of the magnetic elements in this group of islands should be thoroughly known.

To quote from recent reports of the Director of the Coast and Geodetic Survey: "There is great need for a magnetic survey of Alaska, especially in the interior and along the Aleutian Islands. Magnetic maps of Alaska are based on insufficient data and the results at the Sitka Magnetic Observatory, while invaluable, do not give the changes for the entire region. . . . Magnetic data for Alaska are nowhere more than barely sufficient, and in many cases entirely insufficient for placing correct magnetic information on the mariner's charts." This condition was somewhat bettered as regards the Aleutian Islands by the work of Lieut. Jones in 1925, but the work should be extended, should be repeated at an early date, and should be more detailed in regions of local disturbance.

The study of the electricity of the air is increasing in importance owing to its close connection with terrestrial magnetism and to its association with the problem of radio transmission. New additions are constantly being made to our knowledge of correlations between changes in solar activity and variations in the phenomena of atmospheric electricity. The need for additional observations of the electricity of the air cannot be overemphasized, especially in regions similar to the Aleutian Islands, in high latitudes and remote from continental land masses.

So far, no atmospheric-electric observations have been made in the Aleutian Islands except the observations made at sea on the *Carnegie* during the 1915-1916 cruise already mentioned, together with two diurnal-variation series of potential-gradient, ionic-content, and penetrating-radiation observations during her stay in Dutch Harbor. The first of these series was interrupted by fog and mist after eight hours of observations, but the second series was continued for 24 hours and the results agreed well with a 24-hour series taken two weeks later in the Bering Sea. For the potential gradient, the chief component apparently was a 'wave" of 24-hour period, the maximum value coming at about 23^h G. M. T. both at Dutch Harbor and in the Bering Sea. The results at Dutch Harbor were more scattered and of greater range than in the

Bering Sea, possibly owing to the influence of land and of nearby mountains, with rapidly changing conditions of weather. These observations should be repeated at other points in the Aleutian Islands to see if the maximum value occurs nearer the G. M. T. of 17^h to 19^h as determined by Mauchly from a discussion of all the results of ocean observations on the *Carnegie*, and to add confirmation to Mauchly's deduction that this 24-hour wave progresses approximately according to universal time over the entire land surface of the earth.

While the meteorological conditions in the group are not of the best, yet an atmospheric-electric observatory could be operated on some island in the center of the chain and would give results of unique value and importance owing to the absence of smoke and dust disturbances usually found near other atmospheric-electric observatories located near large centers of population. The conditions would be practically the same as exist at sea, due to the distance from large continental areas, and experience has shown that ocean observations have been far less disturbed than land observations.

Only one atmospheric-electric observatory is in operation in the Pacific Ocean, that at Apia, Samoa. An observatory at the Aleutian Islands would supplement greatly the one at Apia in its contributions toward a solution of the many problems of atmospheric electricity in the study of the variations with latitude and with the seasons, of the daily and annual changes, and of the effect of climatic and meteorological changes.

To emphasize the scarcity of magnetic and electric data in these regions, and the urgency of increasing our knowledge of the magnetic and electric conditions in the far north, the following resolutions were adopted at the Madrid meeting of the International Section of Terrestrial Magnetism and Electricity, October, 1924:

> "That the Section deems it highly desirable to call attention to the need of additional magnetic and electric observations in high latitudes, especially north of 60° N. and south of 50° S.
>
> "The section calls attention to the need of additional field observations and observatories pertaining to terrestrial electricity.
>
> "The section recommends the desirability of obtaining magnetic data from high latitudes in years near sun-spot maximum to supplement those near sun-spot minimum already obtained to some extent by certain Antarctic expeditions and that this matter be brought to the attention of future expeditions."

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METEOROLOGICAL OBSERVATIONS IN THE ALEUTIAN ISLANDS

C. L. MITCHELL

Abstract.—The maintenance of regular observing stations in the Aleutian Islands and of uninterrupted communication between them and the Pacific coast of the United States is of very great importance to the Weather Bureau. The U. S. Navy maintains radio stations at Dutch Harbor, Kodiak, and St. Paul, and twice-daily observations are sent from each of these stations.

The importance of meteorological reports from the Aleutian region, as well as from the mainland of Alaska, has long been recognized. It has been thought generally by meteorologists in the past that the Gulf of Alaska is the breeding place of the storms that enter British Columbia from the Pacific Ocean, because of the more or less permanent area of low pressure over that region much of the year and because of the great difference in temperature, especially in the colder months, between that area and the interior of Alaska—a condition favorable to storm development. In recent years, however, the charting of meteorological reports from Japan, the Philippine Islands, the coast of China, and from a constantly increasing number of vessels that report daily by wireless while crossing the Pacific Ocean, has furnished much material for study of the storms of the North Pacific Ocean, and it has been found that all, or nearly all, of the storms that enter British Columbia or our north Pacific coast originate far beyond the Aleutian Islands. Many of them move northeastward over or near Japan and pass near, or south of, Dutch Harbor into the Gulf of Alaska, the so-called permanent area of low pressure simply affording a channel through which the disturbances pass, rather than being their breeding place. Hence the receipt of meteorological reports from the Aleutian Islands is essential in order to have advance information of the approach of the numerous storms that cross the North Pacific Ocean. At present, Dutch Harbor is the meteorological outpost in the Aleutians; but there is great need for an observing station at Attu, the most westerly of the Aleutians, in order to fill in the gap between Dutch Harbor and Japan. The establishment of means of communication with this island remains a problem for the future.

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